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BY LUGER RESEARCH

Review

LpR 111

Sept/Oct 2025

CIE IN THE SPOTLIGHT WITH DIANA WERNISCH

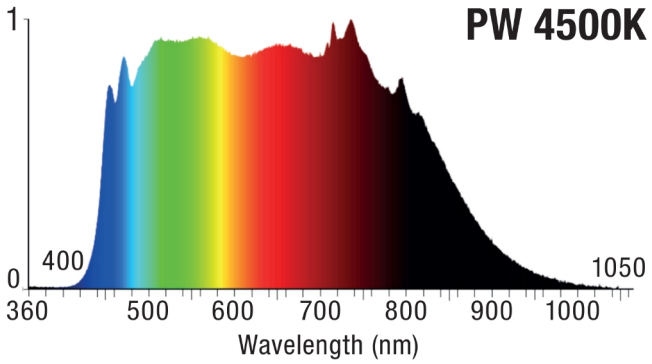
THE HEARTBEAT OF SMART CITIES

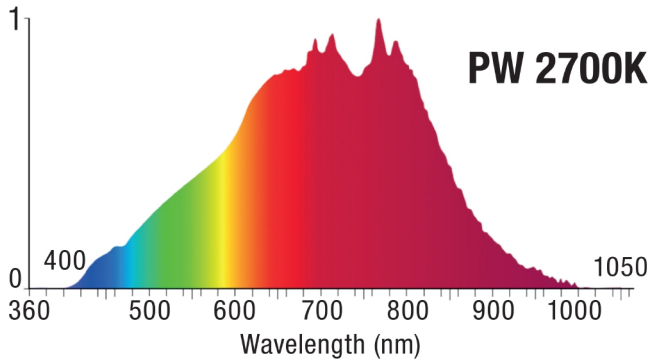
THE POWER OF "INCANDESCENT" LEDS

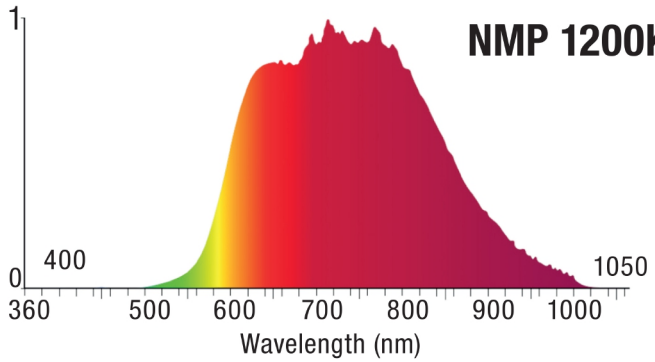
The Global Information Hub for Lighting Technologies and Design

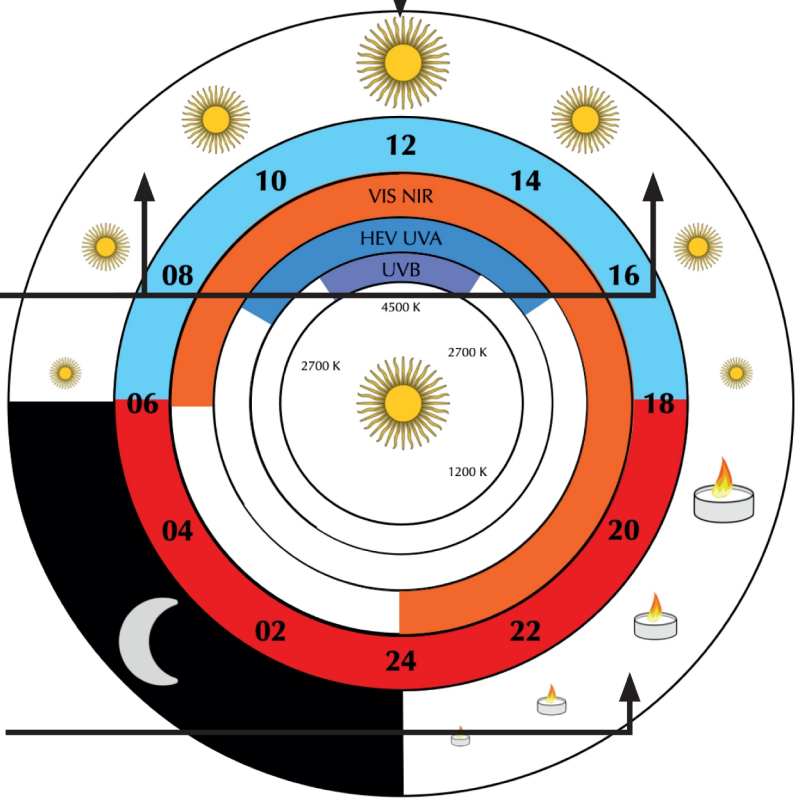
euroLighting
competence in light

LED Light That Finally Feels Right









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Illumination at the Crossroads: Science, Standards, and Human-Centric Design

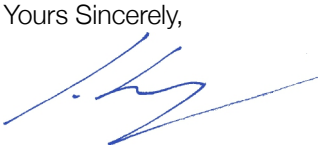
LED professional Review #111 presents a rich mixture of insights, interviews, and reports that capture the current momentum of the global lighting industry. We open with a commentary that repositions the value of lighting through the lens of the "3-30-300 rule." Instead of being regarded merely as a tool for energy efficiency, lighting is framed as a key driver of human performance, health, and well-being. This perspective challenges the industry to broaden its narrative and seize new opportunities where the impact of light on people yields far greater returns than savings on utilities or real estate.

In an exclusive interview, Dr. Diana Wernisch, Secretary General of the CIE, shares her vision for the organization's evolving role in bridging science, industry, and society. With her strong background in international cooperation, she discusses the importance of standards, global collaboration, and digital transformation in shaping the future of light. This theme is expanded by the comprehensive report from the CIE Midterm Meeting in Vienna, highlighting technical achievements and future directions for international standardization.

Policy and regulation are also in the spotlight as LightingEurope calls on the European Commission to adopt uniform rules addressing the environmental and societal impact of Artificial Light at Night. Meanwhile, Dr. Beverly Pasian offers fresh insights into lighting's role in the "heartbeat" of smart cities, drawing on data from more than 6,000 projects worldwide to reveal how safety, sustainability, and social well-being converge.

Innovation is further explored with Gaggione's showcase of optical solutions at GILE 2025, alongside Dr. Alexander Wunsch's provocative article on the potential health benefits of "incandescent LEDs." The issue concludes with part two of Bartenbach's study on sustainable public lighting, outlining both the technological potentials and systemic limitations that must be addressed to meet international climate and policy goals.

Yours Sincerely,



Siegfried Luger

Founder & CEO of Luger Research e.U.
Publisher of LED professional, Trends in Lighting, LpS Digital, and the Global Lighting Directory

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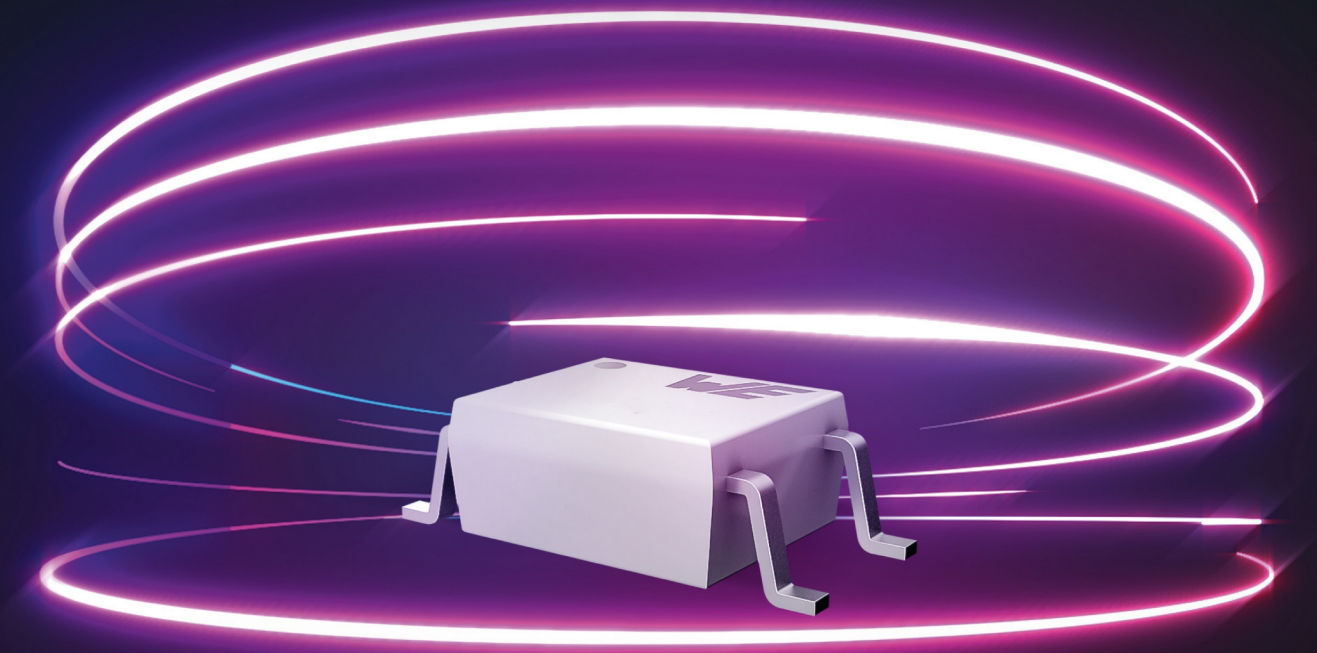

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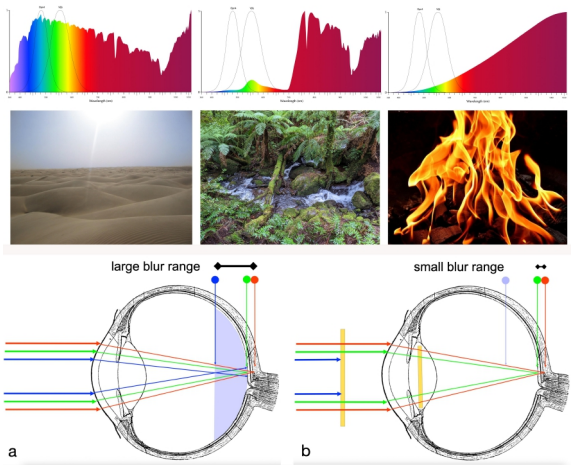
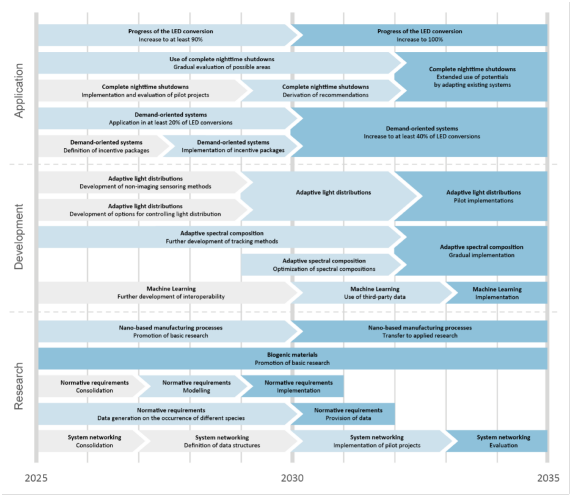
OPTICS

HUMAN CENTRIC LIGHTING



SUSTAINABILITY



ADVERTISING INDEX

From EUR 3 to EUR 300: The Opportunity for the Lighting Industry

Jan Denneman

Jan Denneman is the founder and chairman of the Good Light Group and an ambassador of the Global Lighting Association.

The Good Light Group is a non-profit organization dedicated to promoting good indoor lighting — either natural daylight or electric light that provides similar positive effects on health and well-being. Good light helps synchronize the biological clock, improves sleep quality, increases daytime energy levels, and supports a better mood and long-term health.

With more than 45 years of experience in lighting, Jan has developed deep expertise in the impact of light on human beings. He served as Vice President at Philips Lighting (now Signify), where he held leadership roles in innovation, product development, marketing, and sustainability.

Jan is the (co-)founder of several leading international lighting consortia, including: the Global Lighting Association (Chairman 2007–2017), Zhaga, The Connected Lighting Alliance, LightingEurope (Chairman 2013–2017) and Good Light Group (Chairman since 2019).

Jan shares his expertise on healthy lighting and sleep across multiple social media platforms—including Instagram, TikTok, YouTube, and Facebook—under the name @JanSleepman. On LinkedIn, he is active under his own name.

What if lighting were no longer seen primarily as an energy issue, but as the key to health, productivity and well-being? The 3-30-300 rule shows how an organization's total occupancy costs are typically structured per square foot per year: around €3 for utilities such as energy and water, €30 for rent or capital costs of the building and installations, and €300 for personnel costs such as salaries, social charges and training. These are not fixed amounts, but a rule of thumb popularized by real estate advisor JLL and later picked up by, among others, the industry association NEMA. The aim is clear: to show that even a small improvement in human performance yields far more than major savings on energy or real estate. Yet this rule is scarcely known in the lighting industry, let alone used to demonstrate the value of lighting.

When I give guest lectures to architecture students on light and health, I often ask who knows the 3-30-300 rule. Most of the time, there is silence. Occasionally, someone raises a hand, but they turn out to be referring to the other 3-30-300 rule from urban green policy, which is about trees and parks. Valuable, but not the rule that can give our lighting sector such important insights. Anyone who understands where that €300 comes from, and what it comprises, can immediately see the enormous opportunity we are missing.

The lighting industry has been focusing almost entirely on the €3 category — energy — and to a lesser extent on the €30 category. Thanks to efficient LED systems, the share of lighting in the energy bill has now become negligible. Lighting has made only a limited contribution to the €30 category, as LEDs last longer and reduce replacement costs. That these two categories dominate is not surprising: investors and building owners focus on energy and capital costs, as they are responsible for them. The largest category, the €300 for personnel costs, sits with the tenants or users of the building — and the lighting industry rarely has direct contact with that group. As a result, the effects of lighting on productivity, health and well-being often remain invisible in purchasing and investment decisions, even though that is where the greatest value creation lies.

People are by far the largest cost in any building. The right light at the right time can directly help reduce those costs and increase output. Morning light with the right intensity and spectrum helps to synchronize the body clock, enabling people to fall asleep more easily and sleep more deeply at night. Well-tuned lighting during the working day enhances alertness, concentration and cognitive performance, especially in the morning and after the post-lunch dip. Dynamic lighting can support energy levels during long tasks, while calmer light in breaks helps people to relax and recover.

The effects are felt not only in productivity but also in health and well-being. Daylight or daylight-like electric light boosts the immune system, reduces winter blues and seasonal depression, and lowers absenteeism. A light environment that supports the day–night cycle improves mood and reduces stress. Even a one per cent improvement in these people-related costs is worth more than the total energy costs of the building.

As long as lighting is seen only as a way to save energy, we remain trapped in a spiral of price pressure and declining revenues. The way out is a new focus: innovation that improves how people function and their well-being. That means integrating daylight into design, supplementing it with electric lighting that supports the natural day–night rhythm, and building solid business cases that show how light contributes to better performance, lower absenteeism and greater satisfaction.

Buildings are not constructed to save energy, but to help people perform at their best. It is time for the lighting industry to embrace that reality and make the leap from €3 to €300. With the right light at the right time, we can improve not just buildings, but especially the people in them. And that is real value. ■ J.D.

jan.denneman@goodlightgroup.org

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Exploring Tomorrow – The Top Themes of Light + Building 2026

light-building.messefrankfurt.com

Architecture and technology are evolving worldwide – driven by digitalization, urbanization and the goal of climate neutrality. These forces are shaping how cities expand, how buildings are used, and how spaces are designed. From 8 to 13 March 2026, Light + Building in Frankfurt am Main will spotlight key future issues for the lighting and building services technology sectors. Three top themes will set the agenda for the future of the built environment: “Sustainable Transformation”, “Smart Connectivity” and “Living Light”.

These three top themes reflect the key developments currently shaping the industry. They provide guidance in a dynamic market environment and highlight the technological, design-oriented and societal requirements that are shaping how we will build and live in the future. ”Sustainable Transformation”, ”Smart Connectivity” and ”Living Light” define the central fields of action in lighting and building services technology – ranging from climate-friendly energy supply and digital connectivity to the atmospheric qualities of light. They illustrate how technological innovation, architectural design and system integration can come together to create holistic solutions.

As the world’s leading trade fair for lighting and building services technology, Light + Building 2026 brings together all the key stakeholders – creating space for inspiration, connection and innovation. In a highly dynamic market, it offers orientation, practical solutions and an interdisciplinary forum for future-ready planning, construction and living. Steffen Larbig, Director Brand Management for Light + Building, describes the significance of the top themes for this international innovation meeting point: “We use them to focus attention on the developments shaping the lighting and building technology sectors today – and which will be essential tomorrow. As an international platform, we offer the industry a space for dialogue, direction and fresh impetus. Our aim is to connect professionals from architecture, planning, industry, the skilled trades, real estate and the public sector, to promote exchange and jointly open up new perspectives for the built future.”

A closer look at the three top themes reveals the key content and priorities that Light + Building 2026 will focus on:

Sustainable Transformation

Climate goals, resource responsibility and the energy transition in existing buildings are reshaping the demands placed on tomorrow’s architecture. Under the top theme “Sustainable Transformation”, Light + Building will present how architecture, technology and infrastructure can be brought together to form an energy-efficient whole. This includes systems and technologies for intelligent energy management and efficiency, solutions for the integration of renewable heat sources, as well as the potential of energy storage and smart grid interaction. Concepts for e-charging infrastructure and ecosystems will also be explored, with a focus on planning, load management and lighting design. Integrated urban development solutions that interlink energy, mobility and design form another essential part of this theme.

Smart Connectivity

Buildings are increasingly evolving into digital systems with numerous interfaces. The top theme “Smart Connectivity” demonstrates how intelligent technologies can boost efficiency in planning, operation and usage. This involves smart building infrastructure, IoT and AI in building management, as well as software solutions and digital workflows that simplify daily routines. It also includes BIM and digital twins that connect digital planning with real-life building operations. Cybersecurity and connected security solutions ensure the protection of digital systems, while system integration and predictive maintenance help enable resilient, sustainable building operation throughout the entire lifecycle.

Light is more than illumination – it creates atmosphere, supports functionality, influences wellbeing and transforms spaces into immersive experiences. The top theme Living Light unites aesthetic, functional and technological perspectives, showing how light can be used to design and shape environments. It focuses on adaptive and human-centric lighting systems that respond to time of day, spatial use and individual needs, promoting wellbeing, orientation and productivity. The theme also encompasses high-quality lighting design and technology, the use of light to support health, and lighting solutions in public and retail environments – from streets and façades to targeted product displays. Outdoor lighting concepts for gardens, parks and pathways complement this. Additional impulses are provided by current design trends, materials and emotionally responsive lighting. Lighting solutions for flexible working environments – summarized under the concept of New Work – round off the theme.

The three top themes reflect the topics currently shaping the industry and those that will influence it in the future. At the same time, they provide the thematic framework for the extensive event program of Light + Building 2026. Specialist lectures, guided tours, special presentations and panel discussions will address central issues, examine current developments in greater depth and promote interdisciplinary dialogue. ■

San’an and Inari to Acquire 100% of Lumileds Holding B.V.’s Shares

www.sanan-semiconductor.com

San’an Optoelectronics and Inari Amertron Berhad announced that they have entered into a definitive agreement to acquire Lumileds Holding B.V. and its European and Asian subsidiaries (“Lumileds International”).

“This transaction is the next step of our ongoing transformation. As the LED industry evolves and continues to mature, I am confident that Lumileds International will continue to be successful and accelerate its growth under the new ownership,” said Steve Barlow, CEO of Lumileds International.

The transaction is expected to close by the first quarter of 2026, subject to customary closing conditions.

About Lumileds International
Lumileds International is a global leader in LED technology, innovation, and solutions for the automotive, display, illumination, mobile, and other markets where light sources are essential. Our approximately 3,300 employees operate in over 15 countries to partner with our customers to deliver solutions for lighting, safety, and well-being.

About San’an Optoelectronics
San’an Optoelectronics, is a renowned high-end light-emitting diode (“LED”) chip manufacturer in China. It is listed on the Shanghai Stock Exchange (600703.SH) with annual revenue of RMB16.1 billion (approximately USD2.2 billion) for the financial year ending 31 December 2024 and a market capitalization of approximately RMB60 billion

(or about USD8.4 billion) as of the date of this announcement.

About Inari Amertron Berhad
Inari Amertron Berhad is a renowned technology company in Malaysia, providing Outsourced Semiconductor Assembly and Test ("OSAT") services to the semiconductor industry. Inari is listed on the Malaysian Stock Exchange (0166.KLSE) with annual revenue of RM1.5 billion (approximately USD350 million) for the financial year ending 30 June 2024 and a market capitalization of approximately RM7.8 billion (or about USD1.8 billion) as at the date of this announcement. ■

ams OSRAM sells Entertainment & Industry Lamps Business to Ushio

www.ushio.co.jp

ams OSRAM sells Entertainment & Industry Lamps business to Ushio Inc. for EUR 114 m as first divestment under its deleveraging plan.

"After the successful extension of the Revolving Credit Facility and the placement of additional senior notes, we delivered the first result of our accelerated deleveraging plan in terms of executing divestment options. With Ushio, we have found the perfect new home for our sophisticated, high-end specialty lamps niche-business. At the same time, we are further streamlining our portfolio towards our core markets." said Aldo Kamper, CEO of ams OSRAM.

Sale of Entertainment and Industry Lamps business

ams OSRAM has signed an agreement with Ushio Inc., a global leader in the field of optical technologies, headquartered in Tokyo, Japan, for the sale of its Entertainment and Industry Lamps (ENI) business. The transaction is expected to close until by the end of March 2026, subject to typical closing procedures. The purchase price of EUR 114 million is on a cash-and-debt-free basis. Net deal proceeds will be determined upon final closing accounts at date of closing.

ENI's product portfolio ranges from specialty lamps for infrastructure and cinema applications to extremely sophisticated light sources for semiconductor wafer fabrication equipment (WFE). The profitable ENI business delivered revenues of approx. EUR 170 million in 2024.

Ushio Inc. has about 6,000 employees and provides light units, equipment, systems, and services through developing new light sources and developing and applying proprietary optical technology, serving a multitude of industrial segments.

Executing its balance sheet improvement plan

On 30 April 2025, ams OSRAM announced its accelerated, comprehensive plan to reach its target leverage ratio of net-debt / adj. EBITDA below 2 consisting of various, complementary elements. Amongst these are an improving free-cash-flow performance on the back of a seamless execution of its strategic efficiency program 'Re-establish the Base', structural growth in the core semiconductor business, the disposal of its 8-inch-Kulim facility thereby eliminating the sale & leaseback liability for this factory, as well as the consideration of strategic options for various additional assets (e.g. divestments) with the goal to generate proceeds well above EUR 500 million.

The sale of its ENI Business to Ushio Inc. is the first step in these considerations.

About Ushio Inc. (Head office: Tokyo, TSE: 6925)
Established in 1964. The company manufactures and sells lamps, lasers, light emitting diodes, and other light sources in the ultraviolet, visible, and infrared bands of the spectrum along with optical and imaging equipment incorporating these devices. Numerous Ushio products in the industrial process field, which encompasses the manufacturing of semiconductors, flat panel displays, electronic components and other products, and in the visual imaging field, characterized by digital projectors, illumination, and other products, have large market shares. In recent years, Ushio's operations have expanded to the life science field, most notably medical applications and the environment. ■

Zumtobel Group Shapes the Future of Its U.S. Organization

z.lighting/group

As part of its ongoing strategic review, the Zumtobel Group has decided to cease manufacturing production at its Highland, New York, USA location.

This decision is part of the implementation of the updated FOCUSED [+] strategy, which is intended to align the company's focus on its core markets and align its global production facilities to best meet changing international market conditions and demands. This approach will best enhance the ability to ensure the resilience and long-term competitiveness of the Zumtobel Group and its three strong brands.

Due to the current strained economic situation and the resulting low production volume in the USA, the management of Zumtobel Lighting Inc., USA, has decided to cease production at the Highland facility, which has been structurally unprofitable and significantly underutilized for some time. The Management Board of Zumtobel Group AG supports this decision.

Zumtobel Group AG expects this closure will result in a one-time, non-recurring charge of approximately EUR 9 million. Most of these effects will be recorded in the 2025/26 financial year. However, these one-time effects are expected to be more than offset in the following years.

Approximately 70 employees in production, research & development, logistics, and administration will be affected by the closure.

Sales operations in the Americas to be restructured despite this closure, the Zumtobel Group will continue to maintain a strong sales and marketing presence in the U.S. through a new sales and distribution structure. Sales operations for the Americas will be divided into two independent units: North America and South America. The goal is to continue providing reliable support to existing customers, architects, and planners, while tapping into and expanding in new markets. Future deliveries to the American markets will be handled through the Zumtobel Group's global production and distribution network.

Zumtobel Group AG
The Zumtobel Group is an international lighting group and a leading supplier of innovative lighting solutions, lighting components and associated services. With its Thorn, Tridonic and Zumtobel brands, the Group offers its customers around the world a comprehensive portfolio of products and services. The Group's know-how about the effects of light on people, acquired over decades, forms the basis for the development of innovations and for accessing new fields of business. In the lighting business, the Group with its Thorn and Zumtobel brands, is one of the European market leaders. Through its lighting technology brand, Tridonic, the Zumtobel Group plays a leading role worldwide in the manufacture of hardware and software for lighting systems (LED light sources and LED drivers, sensors and lighting management). The Zumtobel Group's service offering is one of the most comprehensive in the entire lighting industry, including consultation on smart lighting controls and emergency lighting systems, light contracting, design services and project management of turnkey lighting solutions, as well as new, data-based services focused on delivering connectivity for buildings and municipalities via the lighting infrastructure. The Group is listed on the Vienna Stock Exchange (ATX Prime) and currently has a workforce of around 5,300 employees. In the 2024/25 financial year, the Group posted revenues of EUR 1,097.2 million. The Zumtobel Group is based in Dornbirn in the Vorarlberg region of Austria. ■

Nine Innovative Lighting Solutions from Acuity Brands Lighting Selected for the 2025 IES Progress Report

www.acuityinc.com

Acuity Brands, Inc. (NYSE: AYI) announced that nine Acuity Brands Lighting solutions were selected for the 2025 Illuminating Engineering Society (IES) Progress Report, which showcases the year's most significant advancements in the art and science of lighting. Selections were made by an impartial committee that evaluated submissions based on uniqueness, innovation, and significance to the lighting industry.

2025 IES Progress Report inclusions: Aculux® 5º Precision Spot, Eureka® Lattice Ceiling Suspended Luminaire, IVO™ Deep Regressed Downlights and Cylinders from Gotham® Lighting, Holobay™ industrial LED High Bay by Holophane®, Hydrel® Wander Pathway and Step Luminaire Family, REBL LED High Bay by Lithonia Lighting®, Embrace™ Overbed Multi-function Luminaire and Observe™ Cloud troffers by Nightingale™ Lighting.

Aculux 5º Precision Spot provides a very narrow beam that is ideal for high-ceiling spaces where illuminating items from a distance is a necessity. It delivers a powerful punch of light (32,000 CBCP) from a 3" aperture, available in both round and square options. It provides superb color mixing and beam control, ensuring consistent and precise lighting. It also offers color temperature options available in 2700K, 3000K, 3500K, and 4000K at 90 CRI. A wide range of dimming options – including nLight – allows for versatile lighting control, while 2-step binning ensures quality and consistency. The glare-free design features a 45-degree visual cutoff that keeps the ceiling quiet and glare-free. It creates a dramatic effect on points of visual interest, elevating the space with a more intimate and sophisticated feel, and is compatible with all existing AX3 trims.

Eureka Lattice family of luminaires is a one-of-a-kind 3D metal printed fixture. Each Lattice luminaire is crafted as a single, robust form, built with multiple intricate layers that highlight the capabilities of advanced metal 3D printing. Designed to be both functional and expressive, Lattice serves as more than a source of illumination – it becomes a focal point within a space.

The layered structure of Lattice is not purely decorative; it is a purposeful design choice that allows light to filter through in a subtle, ambient manner. This creates an atmosphere that is both inviting and comfortable, demonstrating how lighting design can influence the character of an environment. Available in sphere, cone, and cylinder forms, each luminaire reflects a contemporary approach to material and form. Lattice is positioned as both a lighting solution and a sculptural element, offering a modern aesthetic for those who value detail and craftsmanship.

Gotham IVO Deep Regressed Downlights & Cylinders incorporate Bounding Ray™ Design with an impressive 45-degree cutoff, expertly controlling glare to enhance architectural features while reducing stress and visual fatigue for occupants. Perfect Color™ Technology sets a new industry benchmark with a 0.5-step MacAdam ellipse, far surpassing the standard 3-step ellipse for superior color consistency and uniformity across the IVO family. Additionally, both Downlight and Cylinders provide a versatile range of beam distributions to support layered lighting designs. High center beam distributions from 10 to 60 degrees complement Medium, Medium Wide, and Wide batwing distributions for a variety of applications across multiple layers of light. Trims and optics are tool-free and field-interchangeable, ensuring effortless last-minute adjustments without compromising performance. Exclusive to the Downlight family, a tool-free, plug-in module and driver unit enables quick-connect power

to the light engine for faster, hassle-free field service. Patent-pending push-in wire-form tension springs ensure a secure, sag-free installation. Exclusive to the Cylinder family, choose from a variety of cylinder body lengths available in round or square shapes with pendant, surface, and wall mounting options. The IVO family also features a broad selection of lumen packages from 500-8,000, and trims, including open reflectors and lensed wall wash trims, available in multiple colors and finishes to suit any design aesthetic.

Holophane HOLOBAY introduces the next generation of robust round high bays for use in demanding industrial environments, as well as large indoor, commercial, and educational facilities. These fixtures are designed with advanced electrical, environmental, and thermal ratings to withstand challenging conditions while supporting energy efficiency and reduced total cost of ownership. Constructed with die-cast aluminum and borosilicate prismatic glass, the solution provides illumination with visual comfort and efficiency. Features include a hinged driver door for simplified installation and maintenance, a compact form factor, and a full suite of controls options to accommodate a wide range of applications. HOLOBAY is available in 3 sizes, 5 colors, and 11 mounting options with lumen packages ranging from 12,000 to 100,000 lumens.

Hydrel Wander Pathway and Step luminaire family feature a broad family of luminaires offering multiple mounting configurations - pedestal, semi-recessed and surface mount - that provide visual continuity for pathways, step, and surface lighting applications. With a robust build and exceptional performance, Wander seamlessly blends into its surroundings and minimizes environmental impact with its low-profile design. Uniquely designed to provide a wide lateral distribution that meets IES egress requirements from up to 25FT on-center fixture spacings. Its design, combined with its proprietary precision high-clarity acrylic optic, prevents scattered light from disrupting the night skies and stops light from spilling unnecessarily. Wander offers three tailored distributions for a wide range of applications with no striations or color separation. Options range from very wide lateral spread to long forward illumination to achieve tailored and unprecedented fixture spacing and superior uniformity. Wander is now an approved Dark Sky Pedestrian Comfort Luminaire when the LED surface is mounted below 1.2m (4 feet) and in a downward position. This means these luminaires help to reduce light pollution and preserve the natural darkness of the night sky.

Lithonia Lighting REBL LED High Bay features patent pending micro-prism optics that deliver uniform and comfortable illumination across the entire space up to 186LPW. Packaged in a sleek, yet rugged diecast housing with IP66, NEMA-Type 4X, and NSF2 ratings, REBL's design also integrates a patented flip hook for quick and easy installations and a range of sensor and cord length options that maintain product listings. REBL delivers simplicity without sacrificing performance and provides flexibility for gymnasiums, food packaging areas, warehouses, manufacturing facilities, and other commercial and industrial applications. It is available with UVOLT or XVOLT drivers and narrow, medium or wide distributions. With switchable color temperature and adjustable lumen output up to 55,000L, REBL is rated for reliable performance in environments up to 55°C.

Nightingale Embrace overbed luminaire was created to relieve patient stress due to overhead light. While traditional overbed lighting becomes a direct and ever-present source of glare for the patient, Embrace pushes light outside of direct patient view, reducing glare, and contributing to a calmer setting for the patient. The multifunction patient bed luminaire offers ambient, exam, and night observation modes, with an optional dedicated reading light. Applications include patient rooms, NICU, senior living, long-term care, and recovery rooms.

Nightingale Observe cloud troffers use an innovative optical treatment to create a realistic sky effect that does not impede the exam and ambient modes. The luminaire uses a unique combination of optics and color to create a fixture that is switchable between a biophilic sky mode, soothing ambient mode, and exam mode; the latter modes meet the strict IES recommended light level requirements (RP-29). Patients control their own space either through an intuitive wall switch, or with a pillow speaker control. ■

Cooper Lighting Solutions Recognized for 15th Year in IES Progress Report, Showcasing Six Lighting Innovations for 2025

cooperlighting.com

Cooper Lighting Solutions has once again secured its place among the industry's leaders, earning recognition in the Illuminating Engineering Society (IES) Progress Report for the 15th time in 17 years. This year's achievement celebrates six innovative products—each one advancing efficiency, adaptability, and design in ways that deliver tangible benefits for lighting professionals and the communities they serve.

Cooper Lighting Solutions products featured in the 2025 IES Progress Report include:

HALO SMX Edgeless Surface Mount LED Downlights: With its edgeless design and modern aesthetic, the SMX series pairs visual elegance with performance that meets California Title 24 JA8 energy requirements. Its easy installation into standard junction boxes makes it a go-to choice for projects where efficiency and style need to work seamlessly together.

HALO ML Flex Canless LED Downlights & Adjustables: With a modular, canless design and interchangeable trims, the ML Flex provides high quality light for downlight, wall wash and adjustable applications. This flexibility, combined with precision optics and deep regression, simplifies project planning and speeds installation.

Fail-Safe FLR/FLR2 ArcMed Fully Luminous – Wet Location, High Abuse,

Medical / Cleanroom: Engineered for demanding healthcare, high abuse, and cleanroom settings, the ArcMed FLR/FLR2 series offers a fully luminous lens with IK10 impact resistance and IP66 dust and water protection. The result is a fixture that can withstand rigorous cleaning protocols and is ligature resistant while maintaining consistent, high-quality illumination.

Invue Epic: The Epic combines refined architectural styling with advanced optical control to create inviting, comfortable outdoor environments. Its precision-engineered optics reduce light spill, improving visibility for drivers and pedestrians while preserving the surrounding nightscape.

Metalux Elevate High Bay (Coming Soon): Built for Industrial and Commercial spaces, the Elevate High Bay delivers up to 60,000 lumens with maximum efficacy of 185 lm/W. Superior optical control delivers true aisle distribution out of a round luminaire, while offering various options including integrated emergency egress lighting, active uplight, easy-mount install, and much more. Multiple beam options ensure light is delivered exactly where it's needed, while its durable IP65 design stands up to demanding environments.

High Density Light Engine: The McGraw-Edison High Density Light Square delivers a 40% increase in lumens and a maximum efficacy of 178 lm/W, producing unmatched coverage and spacing while prioritizing efficiency. With a wide range of optical and CCT options, plus IK10 and IP66 protection, it's built for performance in challenging applications.

"Being recognized in the IES Progress Report is always an honor, and having six products selected this year is a true testament to our team's unwavering dedication and relentless pursuit of excellence," said Eric Jerger, VP/GM at Cooper Lighting Solutions. "These innovations go beyond incremental improvements — they solve meaningful challenges for our customers, from maximizing energy efficiency and streamlining installation to enhancing sustainability, improving connected control, and delivering superior lighting performance and design."

About the IES Progress Report: The Illuminating Engineering Society's Progress Report is published annually to recognize significant advancements in the art and science of lighting. Products are evaluated by an expert committee for innovation, technical merit, and meaningful improvement over existing solutions.

Cooper Lighting Solutions delivers forward-thinking lighting solutions and an industry-leading portfolio of indoor and outdoor lighting, lighting controls and smart lighting systems that improve people's well-being, while making buildings, homes, and cities smarter and more sustainable. These solutions are specifically designed to simplify and personalize lighting, solve complex business challenges, and leverage data insights to meet the unique needs of our customers. Cooper Lighting Solutions is a business unit of Signify, the world leader in lighting, and seeks to unlock the extraordinary potential of light for brighter lives and a better world. ■

Organic Lighting Expands UK Presence with New Distribution Partners

www.organiclighting.com

Organic Lighting, the US-headquartered maker of award-winning innovations such as FortaCast inground lighting and OrgaRail illuminated handrail, has secured major sales representation across the United Kingdom. The expansion comes through new partnerships with Aestivo and Chroma Lighting.

The move marks a significant step in Organic Lighting's international expansion strategy and ensures tailored, region-specific support for architects, lighting designers, and building contractors seeking integrated lighting solutions that combine smartly engineered lighting solutions that are easily maintainable with visual elegance.

Aestivo will act as the exclusive representative across Great Britain (England, Scotland and Wales). Steadily building a reputation for their design-led, consultative approach to architectural lighting, the company works with lighting designers and architects in hospitality, retail and commercial spaces as well as landscape architects and building contractors. Organic Lighting's unique flood-proof, drive-over inground lighting and illuminated handrail systems are a key addition to Aestivo's growing portfolio of design- and performance-led lighting solutions from brands across the world.

"Organic Lighting's solutions bring a level of durability, customization and ingenuity that fits perfectly with the types of projects we support," said Greg Russell, Director at Aestivo. "We're always looking for manufacturers who share our commitment to quality, reliability and creativity. Organic Lighting ticks all three boxes."

In Northern Ireland, Organic Lighting will be represented by Chroma Lighting, a highly respected lighting supplier and consultancy that partners with the region's leading architects, electrical engineers and contractors. Based in Belfast, Chroma Lighting has earned a strong reputation for often guiding technically demanding lighting projects from concept through to delivery.

"From outdoor public realm regeneration to high-spec commercial interiors, we pride ourselves on delivering lighting schemes that are both practical and expressive," said Lloyd Crawford, Director at Chroma Lighting. "Organic Lighting's solutions will slot very neatly into the kind of creative designs and functional projects developed by our clients."

For Organic Lighting, the agreements mark the culmination of a targeted effort to build a foundation of local expertise within the UK market.

"Having trusted and knowledgeable partners on the ground is key to delivering the level of service we're known for in North America," said Jonathan Cocking at Organic Lighting managing international sales. "Partnering with Aestivo and Chroma Lighting as partners, we can now deliver comprehensive UK-wide service and support to every customer."

About Organic Lighting: Organic Lighting Systems, Inc was created in 2002 as a sister company to Orgatech Lighting to focus exclusively on color changing LED lighting, and in 2009 with the advent of white LEDs became the first to introduce professional quality flexible lighting strips in the USA. As LEDs advance, so does our mission, which is to create new smart applications in illumination. Our LED products continue our reputation for endurance and meaningful architectural design. Enhanced with inbuilt technology and controls designed to simplify specification and installation, while meeting superior illumination standards and world class specifications. FortaCast and OrgaRail are trademarks owned by Organic Lighting Systems, Inc. ■

Peak Value: ams OSRAM Doubles UV-C LED Efficiency

ams-osram.com

Battling germs with UV-C radiation: disinfection with light is gaining global importance — in hospitals, offices, kitchens, and bathrooms. Even tap water can be disinfected using UV-C radiation. ams OSRAM has now achieved a technological breakthrough in this field within the scope of the evaluation of a new UV-C LED. The LED

delivers over 10 percent efficiency at 200 milliwatts power, a wavelength of 265 nanometers, and a lifespan exceeding 20,000 hours. With these specifications, it can replace conventional mercury discharge lamps in the future. The LED's efficiency has been validated by Germany's National Metrology Institute Physikalisch-Technische Bundesanstalt (PTB).

Eliminating pathogens on surfaces, in liquids, or in the air is crucial for safeguarding human health and the environment — in everyday life and across various industries. Residue-free disinfection using energy-rich UV-C radiation is playing an increasingly important role in this context.

Alongside UV-C LEDs, radiation sources primarily include low-pressure and medium-pressure discharge lamps. Due to their mercury content, these lamps pose health and environmental risks during production, operation, and disposal. The demand for more sustainable alternatives, such as UV-C LEDs, is therefore steadily increasing. So far, however, their efficiency has not yet matched traditional technology to fully compete with established mercury vapor lamps across all applications.

"We are increasingly focusing our research and development efforts on sustainable products. As a leading LED manufacturer, our goal is to unlock and continuously enhance UV-C LED technology to enable an ever-growing number of applications," explains Dr. Ulrich Steegmueller, Senior Vice President Research and Development in Business Unit Opto Semiconductors at ams OSRAM. To this end, the company is working on multiple technological advancements in the areas of epitaxy, as well as chip and package design. The company recently succeeded in optimizing the extraction of UV-C radiation from the LED, thereby increasing the radiation output available for applications. The LED achieved wall plug efficiency (WPE) exceeding 10 percent, while also delivering a long lifespan of more than 20,000 hours. ams OSRAM has thus managed to nearly double the previous LEDs' WPE of around 5.3 percent — with all other conditions remaining unchanged.

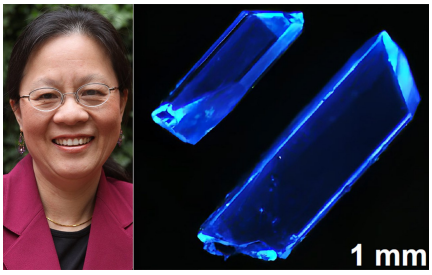
This peak value has also been validated by the Physikalisch-Technische Bundesanstalt (PTB): the institute's measurements confirm a WPE of 10.2 percent. In addition to enhanced optical performance, ams OSRAM has successfully demonstrated that the samples tested exhibit a lifespan as long as that of high-power LEDs currently available on the market.

Peak efficiency and excellent lifespan validation underscore that this is a major technological and sustainable milestone for ams OSRAM's future developments. The new UV-C LEDs are expected to be available from late 2026 and will complement the existing product portfolio for advanced UV-C lighting solutions. The company safeguards its innovations in UV-C LED technology with more than 200 high-quality patent assets, securing a strong intellectual property position in this area. ■

Scientists Develop Deep-Blue LEDs Expected to Greatly Enhance General Lighting

www.rutgers.edu

A Rutgers-led team of scientists has developed an eco-friendly, very stable, ultra-bright material and used it to generate deep-blue light (emission at 450 nm) in a light-emitting diode (LED), an energy-efficient device at the heart of all major lighting systems.



"Deep-blue LEDs are at the heart of today's energy-efficient lighting technologies," said Jing Li, a Distinguished Professor and Board of Governors Professor of Chemistry and Chemical Biology in the Department of Chemistry and Chemical Biology in the School of Arts and Sciences who leads the study. "However, existing options often present issues with stability, scalability, cost, efficiency or environmental concerns due to the use of toxic components. This new copper-iodide hybrid offers a compelling solution, leveraging its nontoxicity, robustness and high performance."

LEDs are lighting devices that use special materials called semiconductors to turn electricity into light in an efficient and durable way. Blue LEDS were discovered in the early 1990s and earned their discoverers the 2014 Nobel Prize in physics.

Blue LEDs are particularly important because they are used to create white light and are essential for general lighting applications.

Li and her colleagues at Rutgers collaborated with scientists at Brookhaven National Laboratory and four other research teams representing national and international institutions in the effort to work on new materials that would improve upon existing blue LEDs.

The researchers involved in the study found a way to make blue LEDs more efficient and sustainable by using a new type of hybrid material: a combination of copper iodide with organic molecules.

"We wanted to create new kinds of materials that give very bright deep-blue light and use them to fabricate LEDs at lower cost than current blue LEDs," Li said.

The new hybrid copper-iodide semiconductor offers a number of advantages over some other materials used in LEDs, scientists said. Lead-halide perovskites, while cost effective, contain lead, which is toxic to humans, as well as having issues with stability, due to their sensitivity to moisture and oxygen. Organic LEDs (OLEDs) are flexible and potentially efficient but may lack structural and spectral stability, meaning they can degrade quickly and lose their color quality over time. Colloidal quantum dots perform well mainly in green and lower-energy LEDs and are often cadmium-based, which may raise toxicity

concerns. Phosphorescent organic emitters may be costly and complex to synthesize.

“The new material provides an eco-friendly and stable alternative to what currently exists, addressing some of these issues and may potentially advance LED technology,” Li said.

The hybrid copper-iodide material possesses favorable qualities such as a very high photoluminescence quantum yield of about 99.6%, meaning it converts nearly all the photoenergy it receives into blue light. Blue LEDs made from this material have reached a maximum external quantum efficiency (the ratio between the number of emitted photons and number of injected electrons) of 12.6%, among the highest achieved so far for solution-processed deep-blue LEDs.

Not only are these LEDs bright, they also last longer compared with many others. Under normal conditions, they have an operational half-lifetime of about 204 hours, meaning they can keep shining for a good amount of time before their brightness starts to fade. In addition, the material works well in larger-scale applications. The researchers successfully created a larger device that maintains high efficiency, showing that this material has potential to be used in real-world applications.

The secret to the material’s impressive performance lies in an innovative technique developed by the scientists called dual interfacial hydrogen-bond passivation. The manufacturing technique significantly boosts the performance of the LEDs four-fold.

“Our processing method minimizes defects that can impede the movement of electric charges at the interface of these hybrid materials,” said Kun Zhu, a former graduate student and postdoctoral associate at Rutgers who is now at the Max Planck Institute in Germany and is the paper’s first author. “This approach could be a versatile strategy for generating high-performance LEDs.”

If the LED can be imagined as a sandwich with different layers, each layer has a specific job, such as emitting light or transporting electrons and holes. Sometimes, the emissive layer doesn’t interact perfectly with its interface layers, which can reduce efficiency or shorten lifespan. The technique eliminates such problems by forming hydrogen bonds between the layers to create better connections.

“Overall, this type of new material is paving the way for better, brighter and longer-lasting LEDs,” Li said.

Other Rutgers scientists contributing to the study included Deirdre O’Carroll, associate professor, and Nasir Javed, doctoral student, of the Department of Chemistry and Chemical Biology and Department of Materials Science and Engineering; and Sylvie Rangan, assistant research professor, and Leila Kasaei, postdoctoral research associate, of the Department of Physics and Astronomy.

The research was funded by the U.S. Department of Energy. ■

Empowering the Future of Lighting — LS2025 Welcomes Final Opportunities Despite Closed Call

ls2025monastir.com

LS2025, the IEEE Sustainable Smart Lighting World Conference, is set for December 8–10, 2025, in Monastir. While the official deadline for the 2-page abstract submission passed on July 20, the organizing committee is announcing a rare, final opportunity for exceptional abstracts to be reviewed — offering last-minute contributors a chance to present at this global forum.

LS2025 will bring together leading researchers, industry experts, innovators, and policymakers from across the globe to explore cutting-edge developments in sustainable and smart lighting. The three-day program will feature keynote addresses from internationally recognized experts, interactive technical sessions, and workshops focused on real-world applications that address energy efficiency, environmental sustainability, and human well-being.

“Our program is already shaping up to be truly exceptional,” said Prof. Georges Zissis, Chair of the LS2025. “But we know that innovative ideas don’t always arrive on schedule. That’s why we’re allowing a short extension for remarkable late abstracts that deserve to be shared with the world.”

Late submission slots will be allocated on a first-come, first-served basis, subject to relevance and quality.

Event: LS2025 – IEEE Sustainable Smart Lighting World Conference
Dates: December 8–10, 2025
Location: Monastir, Tunisia

Theme: Smart and Sustainable Lighting for a Brighter Future ■

LEOTEK Launches KarbonCobra™

leotek.com

LEOTEK Electronics USA LLC, headquartered in Silicon Valley and a global leader in innovative LED lighting technology for street and area lighting, proudly announces the launch of KarbonCobra™, a next-generation cobra head streetlight engineered to meet the evolving needs of modern cities with smarter performance, lower environmental impact, and future-ready connected technology.

Designed for utility, municipal, and DOT applications, KarbonCobra™ combines high performance with a compact, lightweight form factor that reduces installation and maintenance costs while minimizing LEOTEK’s carbon and environmental impact. With seven optical distributions and low glare comfort optics, it enhances driver safety and visual comfort, addressing common nighttime visibility challenges such as eye fatigue, distance distortion, and delayed reaction times.

Available in three sizes with scalable lumen packages (100W–400W HID equivalent) and delivering up to 176 lm/W efficacy and lumen outputs ranging from 1,200 to 29,000 lm, KarbonCobra™ is engineered with your lighting needs in mind. ISO 14061-1:2018 carbon verification ensures that both operational costs and environmental impact are reduced.

A future-ready embedded node and software options make smart city integration seamless. With over 3 million LED streetlights and 35 million LED traffic signal units deployed, LEOTEK is trusted for its proven reliability. Backed by a 10-year warranty, IK10-rated durability, and UL Wet Location certification, KarbonCobra™ performs well in extreme weather conditions (-40°C to +50°C) and maintains at least 90% of its output at 60,000 hours. All this to ensure top notch, long-term Total Cost of Ownership (TCO).

”KarbonCobra™ is more than a streetlight. It is a reflection of LEOTEK’s leadership and commitment to shaping the future of intelligent, sustainable city infrastructure through innovation, performance, sustainable design, and service,” said Ewing Liu, Chief of Staff and Vice President of Sales at LEOTEK. ”As cities strive to become cleaner, safer, and

more connected, KarbonCobra™ delivers the efficiency, reliability, and future-ready features needed to power the infrastructure of tomorrow. KarbonCobra™ is our bold step forward in our mission to illuminate the path to net-zero urban environments worldwide and AI Roadway Infrastructure Solutions."

About LEOTEK Electronics USA LLC: Founded in 1992 in California's Silicon Valley, LEOTEK Electronics USA LLC is a subsidiary of the LITEON Technology Group and operates from its headquarters in San Jose, California. As the leading global provider of intelligent LED roadway lighting products, LEOTEK has served the roadway infrastructure of over 30 countries, including North America, Europe, the Middle East, and the Asia-Pacific region.

LEOTEK is dedicated to driving urban transformation through its intelligent lighting solutions, which integrate AI and IoT for advanced road automation and operational services. With a strong focus on safety, ecology, and low carbon impact, LEOTEK strives to create intelligent, clean, and net-zero cities, setting new standards for innovation and sustainability in the lighting industry.

Today, the company is recognized as a global leader in LED lighting technology, specializing in the manufacture of innovative LED lighting products for various applications, including traffic and transit, street, and area lighting. LEOTEK is renowned for its commitment to developing sustainable, energy-efficient lighting solutions that reduce energy consumption and maintenance costs. ■

Bytech Achieves Landmark AEC-Q102 Certification for Automotive-Grade UVC LED Technology

zsbytech.com

Bytech announced that it has become the first domestic company to achieve AEC-Q102 certification for automotive-grade UVC LED products, a significant milestone that places China's UV LED technology into the global automotive supply chain for the first time.

The newly certified 275 nm deep-ultraviolet (UVC) LED delivers 99.99% sterilization efficiency, making it an ideal solution for improving in-vehicle health and safety. By disrupting the DNA or RNA of bacteria and viruses, UVC radiation prevents microbial growth and reproduction, effectively neutralizing airborne and surface-level pathogens.

The certified product features a full inorganic airtight package constructed from aluminum nitride ceramic, metal, and hard glass, ensuring exceptional durability and reliability. Key specifications include:

- Wavelength: 270–280 nm
- Optical Output: approx. 17 mW @ 100 mA
- Voltage: 5–7 V
- Viewing Angle: 120°
- Service Life: >20,000 hours
- Electrostatic Protection: ≥ ±8,000 V (HBM)
- RoHS compliant

Designed with low thermal resistance and a thermo-electric separation substrate, the LED achieves efficient heat dissipation and long operating stability. Patent protection further strengthens its competitive edge.

Features and Benefits

- Strict Certification: AEC-Q102 approval demonstrates high resistance to heat, vibration, and demanding automotive conditions.
- High Sterilization Efficiency: 275 nm UVC rapidly neutralizes bacteria and viruses, purifying both cabin air and interior surfaces.
- Safe Operation: An intelligent protection mechanism eliminates ozone leakage, ensuring safety for both passengers and vehicle systems.
- Fexible Integration: Optimized for automotive HVAC systems, car purifiers, and other in-cabin applications; available with OEM/ODM customization.

Beyond the automotive sector, Bytech's UVC LED technology supports a wide range of sterilization, disinfection, and air purification use cases. These include water and liquid treatment, food preservation, VOC reduction, and biochemical analysis—making it a versatile solution for industries where hygiene and safety are paramount.

"This achievement not only validates the quality and reliability of Bytech's UVC LED products, but also paves the way for wider adoption in the automotive industry," said a company spokesperson. "With this certification, we are opening the door to new applications and setting the foundation for safer, healthier driving experiences worldwide."

Bytech plans to continue expanding its product line to meet automotive regulations and international standards, with a strong focus on sustainability and innovation.

About Bytech: Bytech is a leading developer of advanced UVC LED technologies dedicated to creating safer, cleaner, and more sustainable environments. The company's product portfolio includes sterilization and disinfection solutions for automotive, consumer, and industrial applications. Bytech's commitment to quality and innovation ensures reliable, high-performance solutions for partners worldwide. ■

Nichia launches µPLS Mini and DominoPLS at ISAL 2025

www.nichia.com

Nichia will present its most comprehensive portfolio of Pixelated Light Source (PLS) solutions for adaptive driving beam (ADB) headlamps at the International Symposium on Automotive Lighting (ISAL) held in Darmstadt between September 22 – 24, 2025.

The Pixelated Light Source family has grown to include the µPLS alongside two fresh additions — the µPLS Mini and DominoPLS — enabling car makers and system integrators to scale glare‑free headlighting from entry‑level ADB applications to high‑definition projection.

Nichia's PLS lineup spans three tiers, ensuring the right balance of performance and cost for every vehicle class. DominoPLS, for instance, is a simplified modular platform designed to support popular small cars transitioning from halogen or conventional LED systems. Its plug-in 'Domino' LEDs enables more advanced dynamic beam control and reduced optical stack height, allowing designers to upgrade to ADB without needing to retool entire lamp housings. Indeed, the tile-like structure of DominoPLS emitters supports thin, customizable headlamp designs such as integration directly into bumpers.

Nichia's µPLS Mini (MicroPLS Mini) combines a proprietary 3,000+ pixel-range micro-LED matrix with Infineon's LITIX™ driver ASIC based on the same technology as the first µPLS (MicroPLS). The product enables individually addressable pixel dimming, higher brightness and symbol projection compared to low and mid-LED count ADB solutions. Additional electronic interfaces are included for simplification of the integration in existing electronic architectures. Therefore, MicroPLS Mini brings digital ADB capabilities to a

broader car market while maintaining a cost-effective bill of materials.

Nichia's compact MicroPLS is a pioneering solution already used in vehicles such as the Porsche Cayenne. First introduced in 2023, the High-Definition (HD) light engine is ideal for headlamps developed in premium and upper-mid-range vehicles. The device is capable of sophisticated image projection using over 16,000 individually addressable pixels. This level of precision enables the headlamp to create sharp, glare-free cut-outs around oncoming traffic while maintaining full illumination elsewhere on the road, as well as enabling dynamic light projections, including on-road symbols and personalized 'welcome home' lighting scenarios — blending safety, innovation, and a premium driving experience.

"By extending our PLS technology to both lower-end and higher applications, we are empowering every automaker to deliver the safety of glare-free lighting and the communication possibilities of road projection, whether they are building a flagship EV or a cost-sensitive city hatchback," said Yusuke 'Karl' Yamazaki, Vice President of Automotive at Nichia Europe GmbH. "With the introduction of DominoPLS and MicroPLS Mini, we now offer OEMs a road-tested path to fit the appropriate ADB headlamp to match their performance and budget needs, all supported by a proven technology stack."

Nichia's expanded portfolio directly addresses key market trends such as the growing adoption of glare-free lighting. The technology's low profile and energy efficiency also benefit electric and autonomous vehicles by freeing up fascia real estate for sensors plus saving weight and power to extend driving range and contribute to meeting sustainability goals. Furthermore, it supports the industry's shift toward software-defined lighting, enabling over-the-air updates for new projection functionality.

At ISAL 2025, Nichia will feature Pixelated Light Sources at Booth 2 in the Darmstadtium Congress Center. ■

Salas O'Brien Welcomes Lighting Design Alliance

salasobrien.com

Salas O'Brien announced that Lighting Design Alliance has joined its growing team, uniting two powerhouses in the built environment. Renowned for award-winning lighting projects, Lighting Design Alliance brings a global portfolio of high-profile projects including Jio World Centre in India, Chimelong Spaceship Marine Science Park in China, and The Londoner Macao.

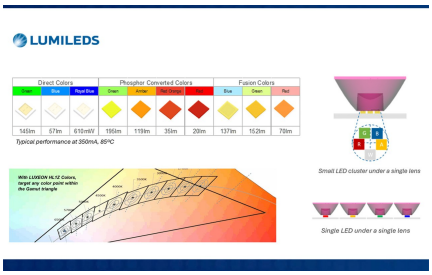
"Lighting can have such a positive and dramatic impact on the human experience. We couldn't be more excited to have such an amazing team and talents join us", said Darin Anderson, Chariman and CEO of Salas O'Brien.

Lighting Design Alliance has been at the forefront of architectural lighting design for over three decades, earning a reputation for groundbreaking design that balances aesthetics, functionality, sustainability, and technology. ■

LUXEON HL1Z Color Line Simplifies Multi-Color LED Application Development with Chip Scale Packaging and Uniform Focal Length

lumileds.com

Lumileds' new LUXEON HL1Z Color Line is a high-power, chip scale package (CSP) portfolio of 10 direct and phosphor converted colors that share a common focal length and footprint. Offered in small color bins and with narrow forward voltage bins, these LEDs deliver better color uniformity, better efficacy and thermal management and more consistent behavior at operating conditions.



Superior Color Mixing: The undomed 1.4mm x 1.4mm emitters feature top emission of the light. With or without optics, the top emission prevents cross fading or interference between different colors and therefore better control of the resulting light and color. Their very small size, high current capability, and 85ºC binning allow for higher density arrays in a smaller space positioned under single or multiple optics.

Colors, CCT Tuning, or Color Tunable: With direct colors, phosphor converted colors, unique, non-saturated Fusion colors, and the LUXEON HL1Z white portfolio, it's easier than ever to create single solutions that deliver color, high-quality white light with CRI well above 90, and dynamic lighting that can be purpose-tuned for an interior design or even human centric lighting. Lumileds engineers have developed implementation tables to make it simple to design the desired illumination.

Driven by Application Requirements: Lumileds continues to add to its color portfolio not because it's technically possible, but because every LUXEON Color portfolio serves different application objectives. For example, the new LUXEON HL1Z color emitters are one-sixth the size of a LUXEON 2835 color emitter and deliver three-times the power. For entertainment, spot, and many other intense color dependent applications, LUXEON HL1Z will prove to be the only cost and performance appropriate solution. Of course, for many strip and linear applications LUXEON 2835 will continue to deliver the best cost/performance option in the market.

Lumileds CSP Innovation: Engineers at Lumileds pioneered CSP technology in 2013 with the company's LUXEON Flip Chip and has continued development over the last 12 years. Lumileds' CSP LEDs do not require an additional sub-mount or substrate, are smaller than comparable LEDs with the same size chip, and can be directly attached to level 2 boards. Particularly useful in directional applications, LUXEON CSP LEDs offer better thermal contact, higher current densities, very high reliability, superior long-term color stability, and easy surface mount assembly with standard equipment.

Immediate Availability: LUXEON HL1Z Color Line LEDs are immediately available through Lumileds distribution network. Lumileds engineering support teams offer resources and development tools to assist customers with color, tunable white, and dynamic white lighting solutions.

About Lumileds: Lumileds is a global leader in LED and microLED technology, innovation, and solutions for the automotive, display, illumination, mobile, and other markets where light sources are essential. Our approximately 3,500 employees operate in over 15 countries and partner with our customers to deliver never before possible solutions for lighting, safety, and well-being. ■

Philips Hue's Play wall washer offers easy setup and control through the Hue ecosystem. Users can personalize features such as intensity, speed, brightness, and positioning. An intuitive 3D drag-and-drop feature in the Hue app enables precise customization of light positioning and direction. Hue Play wall washer works seamlessly with the Hue HDMI Sync box, TV and PC Sync apps, all Hue accessories, and voice assistants such as Amazon Alexa, Google Assistant, and Apple HomeKit.

"The Hue Play Wall Washer is a bold step toward our vision of lighting as a cornerstone of immersive entertainment. Its sleek design and powerful light projection transform everyday spaces into dynamic, content-driven experiences." – John Smith, Business Leader for Philips Hue at Signify. ■

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Connecting Research and Everyday Life: The CIE's Vision for Light – Dr. Diana Wernisch, Secretary General, Int. Commission on Illumination (CIE)

Dr. Diana Wernisch
"The CIE brings science, industry, and society together to shape the future of light."

In this exclusive interview, Dr. Diana Wernisch, Secretary General of the International Commission on Illumination (CIE), shares her perspectives on the organization's mission, evolution, and future. With a strong background in international research cooperation, academic publishing, and scientific infrastructure, Dr. Wernisch discusses what motivates her work in light and lighting standards, how the CIE bridges science, industry, and society, and why global collaboration and digital transformation are essential to shaping the future of lighting.

https://cie.co.at

LED professional: **Dr. Wernisch, could you briefly tell us about your professional background and how you became involved with the CIE?**

Dr. Diana Wernisch: Of course, let me first thank you for the great opportunity of being interviewed for your magazine.

Regarding my professional background, I have a business and management education from WU – Vienna University of Economics and Business and I have done some research work and my PhD in the field of higher education and research management. I have worked in the field of international cooperation in research and education, as well as in academic publishing and the development of scientific infrastructure and publication services for researchers. I have also managed transfer-oriented research centers, one of them focusing on increasing young people's interest in STEM careers. So, my work as a manager has long been characterized by contexts in which it is essential to understand and bridge different sectors or fields.

This is also how I got involved in the CIE. My role as the Secretary General is centrally positioned in the global organization. From the beginning, I considered the CIE, with all its different roles, disciplines and fields that define, characterize and drive the organization, to be a really interesting organization to work at. I was immediately enthused when I read the job opening. In addition, I was looking to move back to Austria – as I am Austrian – and back to the wonderful city of Vienna. I have been in my role now for 2 years and it's great to manage and further develop the CIE together with our Governing Board. It's a fascinating organization and an inspiring job that allows diverse interactions with our members – from national committees to industry leaders, with the expert volunteers who really carry the work and essence of the CIE, and with all our partners and stakeholders.

LED professional: **What motivates you personally about working in the field of light and lighting standards?**

Dr. Diana Wernisch: For me, it's the combination of the impact that standards can have – not only on industry and economic development but also, eventually, on the everyday life of people, our society and environment, and our well-being. And this potential impact, together with the unique contribution that the CIE is successfully delivering in the field is what makes it worthwhile: Good standards and regulations need good science. You need to be able to base a framework, rules, procedures, etc. on actionable bodies of knowledge, like the CIE produces. The CIE knowledge is essential for good standards and regulations, and thus also for innovation and the prosperous developments of our economies and societies.

What is unique about the CIE is that we are an international scientific organization and a standards-developing body. This dual role positions us as an essential actor and producer in the standards and regulatory ecosystem. Even more, CIE as a global community also has an important role in the dissemination and diffusion of actionable knowledge and standards into practice. Learning-oriented CIE events such as our tutorials, workshops, and webinars also play an important role here. No other organization bridges different sectors such as academia, science and research, and standardization, with industry, practice, and society as seamlessly as the CIE does.

LED professional: **For readers who might not be fully familiar with it, how would you summarize the mission and global role of the CIE today?**

Dr. Diana Wernisch: Let's quickly revert to the CIE statutes for this: CIE is devoted to the worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, color and vision, outdoor and indoor lighting and design, photobiology, and image technology. Our mission is to advance the broad field of light and lighting by acting as the global body and platform in the field.

As an international scientific organization, it's important for us that we are fully recognized as a member of the International Science Council. The ISC membership is key for us as it links us to neighboring or foundational fields and disciplines such as physics, optics, or chemistry, astronomy, remote sensing, you name it!

Our scientific role also enables the CIE to act as a relevant body to produce consolidated and reliable knowledge and publish International Standards and Technical Reports in light and lighting. As a standards-developing body we

have close partnerships with ISO, IEC, and CEN/CENELEC. You can perhaps judge the role of the CIE by how its work has been taken up: The majority of the publications of the core ISO committee in light and lighting originate from the CIE, and we value this partnership through extensive cooperation. Another example is CIE S 009, on photobiological safety of lamps and lamp systems, which with its derivative publication IEC 62471 is referenced in around 60 other documents.

An important aspect of our mission context is that the CIE really covers the broad field of light and lighting: This is reflected in the six Divisions whose work ranges from photometry to photochemistry to image technology. To have this scope included in one organization is complex but also essential to our global leadership role: This is because the CIE provides an umbrella under which all light- and lighting-related topics can be discussed, linking different disciplines and integrating neighboring fields.

We are in a position to act as such a platform exactly because we have manyfold linkages. Many experts do not only work in the CIE but also in other organizations, such as International Commission on Non-Ionizing Radiation Protection (ICNIRP), International Color Consortium (ICC), Lighting Urban Communities International (LUCI), International Astronomical Union (IAU), World Health Organization (WHO), etc. Likewise, in the CIE, experts from academia work together with experts from industry and governments. This is why the CIE is also the right forum to work on and discuss complex and multi-dimensional topics related to light and lighting.

And finally, I want to single out our mission and role to be the place for young experts from all over the world who will continue on to academic or industry careers, to learn from the best, and to build high-quality, diversified networks already at a young age. The professional spirit of the CIE community is a big asset in that respect.

LED professional: How has the organization evolved in recent years to respond to new technological and environmental demands in lighting?

Dr. Diana Wernisch: That's challenging to summarize in brief but let me pick up a few points here which are evident in the work of our technical committees and research fora across the six CIE Divisions.

One development and demand is that lighting-related aspects are and need to increasingly be discussed within more integrated settings and concepts, such as lighting as part of indoor environmental quality, lighting in smart buildings, or (road) lighting and energy efficiency within smart-city concepts. Similarly, from an integrated perspective, a topic needs to be discussed taking into account multiple dimensions. For example, urban lighting is being and can be discussed from an energy-efficiency perspective, in view of smart-city concepts, urban development concepts at large, or in view of potential problems from obtrusive light on nature, animals and humans.

I mentioned before that the CIE is used to multi-sectoral and multi-disciplinary work. Nevertheless, these developments also require our organization to adapt continuously. For example, I have observed a tendency of more and more cross-divisional topics in the CIE. These developments also require the CIE to continuously and actively establish links to possibly new relevant neighboring fields and try to create good overlaps with such communities, for example by bringing more of those experts into the CIE collaborative space.

I also have the impression that in the CIE, we increasingly work on topics and projects that create even stronger linkages between the CIE divisions. For many of those links, digitalization is a strong driver, and this is a second important technological development that the CIE is responsive to and which is visible in different areas: thematic projects on the one hand but also on a more abstract and strategic level.

One practical example is that the CIE, since 2023, has released many datasets from CIE publications as stand-alone electronic datasets, fully referenced with all necessary metadata, ready to be used by industry and research. This is a service that supports progress and innovation.

Another future-oriented initiative that the CIE is involved in is the development, implementation and promotion of the digitalization of the International System of Units SI (the so-called SI Digital Framework[1]), as part of the wider digital transformation of the international scientific and quality infrastructure. To emphasize this, CIE has signed a Joint Statement of Intent[2] together with other leading international organizations such as BIPM, ISO, IEC, ILAC (International Laboratory Accreditation Cooperation), or ISC.

In 2026, CIE will take over the coordination of activities of the SI signatories. The digitalization of vocabularies and terms and definitions, will be a topic discussed in this context and so this will also link to CIE's light and lighting terminology (ILV) and its digital version (e-ILV). Further activities are new and globally harmonized data formats for electronic transfer of optical radiation data for luminaires, lamps and LED modules (TC 2-99), or the newly established TC 2-100 *Software Validation Spectra, Derived Quantities and Metrics* which are both TCs supporting the digital transformation of the industry and society.

LED professional: Are there any cross-disciplinary or sustainability-focused projects the CIE is involved in that you'd like to highlight?

Dr. Diana Wernisch: There is one new initiative of the CIE I would like to mention. It's a public communication effort we are making in a project entitled *Understanding science – Understanding light*[3] for which we have also received funding from the Vienna Business Agency. In this project we are making an explicit effort to make the public more aware of lighting and its importance, and we try to show how science, research and research-based regulations in light and lighting are relevant to people's lives. We have chosen two topics to focus our events and communication on: Light and health is one theme and light pollution is the second one. Both of the topics are cross-disciplinary and also inherently relate to sustainability aspects. They are not only important areas of work in the CIE but, importantly, these topics also get the attention of people. We use them to bring more awareness, more knowledge and more understanding to the general public, showing how light and

[1] https://si-digital-framework.org/
[2] https://www.bipm.org/en/liaison/digital-transformation
[3] https://cie.co.at/news/cie-project-understanding-science-understanding-light

lighting actually affects their lives. I am happy we got this project funded as it's a valuable contribution to the recognition of the field and public awareness about it.

LED professional: The CIE just held its mid-term conference in Vienna. What were some of the highlights and key outcomes of the event?

Dr. Diana Wernisch: It was great to see that strategies of the past years – which included forging ever stronger links to partner organizations and stakeholder communities – resulted in very high registration numbers. 430 participants attended the scientific conference and 240 (plus around 70 online) attended the CIE Division & TC meetings where the technical work is progressed. An analysis of our registration data also shows that the CIE has been successful in attracting new groups of participants which enlarges and extends the CIE community. This is an indicator that our focus on continuing to strengthen our networks with various partner organizations and stakeholders is purposeful.

Another highlight was the composition of our audience at CIE meetings. Our data shows that in 2025 around one third were academics from universities, around 25% come from industry, 10% from research labs and institutes, 10% from architecture/design/engineering and another almost 10% from governments/regulatory bodies etc. This mix of the audience is fantastic as it speaks to the role of the CIE that I described above in bridging fields and sectors. I think it also underlines the strong interest from those various groups to take notice of the latest research results in various fields of light and lighting and the worth of the CIE conference to benefit their own career and organizational goals.

So, CIE 2025 was a milestone to integrate initiatives we have worked on over the past years and months, and to set the grounds for continued and new cooperations ahead.

Importantly, we've had official delegates and representatives from some countries and regions in which we want to enlarge our reach and eventually build new light and lighting communities. For example, we've established strong new connections for a longer-term collaboration in the Middle East and Northern African (MENA) regions.

I was also delighted to see how many organizations actively made efforts to link their work to the CIE community. For example, the ICC by intention held its meetings in Vienna in overlap with our conference so that the communities could mix. Similarly, the BIPM's Consultative Committee on Photometry and Radiometry (CCPR), which works very closely with the CIE, met prior to the conference and many CCPR members also joined the CIE Midterm Meeting. Further, we've had the chance to renew our relations with LUCI and we were also very pleased to welcome Dark Sky representatives at CIE 2025, to mention just a few. To see these organizations joining us in discussions and showing interest in potential future cooperation is highly inspiring and we look forward to continuing our work with all of them.

One of my personal highlights was that one of my staff members spontaneously guided a tour with a group of students to our CIE Central Bureau, where we also store some old documents and photographs of the CIE presidents since 1913. It was nice to see that these young people were so enthusiastic and proud to be part of the CIE community. In general, I have the feeling that the strong drive and spirit which carries the organization where you can learn, contribute, make an impact and form really good networks has also been felt as a spark during CIE 2025.

LED professional: Were there any major observations, trends, or research findings that particularly stood out to you?

Dr. Diana Wernisch: Since you also have a scientific and technical report on the CIE Midterm Meeting Vienna 2025 in this issue, I will take the opportunity to focus on some personal observations that stood out for me.

One prevalent aspect was that the 2025 scientific conference seemed to serve as an exchange forum all around the topic of urban and outdoor lighting, its positive but also detrimental effects on nature and humans. We saw a lot of new research in this field being presented in sessions at the peer-reviewed CIE conference program. The International Scientific Program Committee had also selected related topics in the curated section of the program: we had a keynote on astronomical observations and light pollution and a Division 6 workshop on the effects of electric light on insects. We even had policy representatives from Czechia traveling to the CIE conference to discuss these issues with us.

So, while the topic of obtrusive light and light pollution is far from new (CIE , for example, in 1980 published its guidelines for minimizing urban sky glow near astronomical observatories), it shows a renewed drive emerging around these topics in the CIE, and with new groups also joining the discussions and work within the CIE. During the Division & TC Meetings program that took place after the conference, the CIE held a discussion meeting where current, new and future lines of work within the CIE that all relate to obtrusive light and light pollution was discussed further with experts from several different CIE Divisions.

By the way, the CIE has a Position Statement on obtrusive light and light pollution which will be coming out shortly.

Another aspect is that light and health continues to be an important topic in the CIE. We've seen both a keynote lecture from a world-famous expert in this field – Prof. George Brainard – coupled with many presentations of papers and posters of younger colleagues, all making up new frontiers becoming visible in the field of high personal, public and industry relevance.

Further, there are very dynamic discussions arising from the image technology research work and industry needs – this is CIE Division 8 – and I have observed new possible work items for the CIE that were discussed during the scientific conference, so I can only recommend to follow-up in the CIE newsletter where we always inform about CIE upcoming work and calls for experts.

LED professional: How do you see the role of international cooperation in lighting science and standards evolving over the next decade?

Dr. Diana Wernisch: In science and research, knowledge exchange is an important factor to advance any field and from that perspective, international cooperation is a key enabler in lighting science and research, and -in the long-

term- for innovative capacities in the field.

In general, I think it will be necessary to try and extend international cooperation and include countries and regions that are underrepresented today in international fora and networks. It can become a problem for both lighting science and for standardization, if we are missing a part of the relevant contexts, dimensions, perspectives, groups, countries or regions. In the long run, we might not only be overlooking their expertise but also their specifically relevant perspectives that are important for the global applicability of research conclusions, knowledge bodies and also standards and regulative information. It's a problem in this context that some researchers might simply lack the funds to join our discussions. This can have an effect on the applicability of our consolidated knowledge body and so I find it important to think about ways to integrate all world regions well. The need for greater attention to diversity, equity and inclusion is also a key theme of CIE's Research Strategy (https://cie.co.at/research-strategy).

Further, my opinion is that international cooperation in the field will need to continuously scan its environments and make efforts to extend both reach and inclusiveness. Based on what I said before on more integrated concepts being discussed, it means we also need to integrate new communities into the light and lighting ecosystem. For the CIE, this means, for example, including researchers from quantum radiometry, or those working on energy efficiency.

Finally, I am an advocate of a parallel and coordinated approach between science and standards, which – in the CIE quite naturally – comes with a strong appreciation of the worth and practical usefulness of having a reliable, globally consolidated body of knowledge in light and lighting that is available for use and integration into the standardization work, within and beyond the CIE.

Consequentially, because science, research, innovation and standards have intricate links, I am advocating for a close relation of innovation-oriented companies to the CIE. Luckily, we already see this today with many innovation- and research-oriented companies seeking close links to follow the newest developments in research and (future) standardization projects, such as by joining CIE conferences and the CIE Supportive Membership program. This is a member program designed to closely link companies to the newest developments within the CIE.

LED professional: **What are your personal goals as Secretary General in the coming years — and what would you like to see CIE achieve?**

Dr. Diana Wernisch: First of all, I will work to support the enthusiasm and drive that I feel in the organization at the moment that has its roots, I think, in the successfully completed governance reform and the strategic directions we are taking.

In addition, we will continue our work on securing and enlarging the reach and membership of the CIE. In a long-term perspective, it would of course be a goal to establish further National Committees and Associate National Committees globally, especially in regions that are currently under-represented in many international organizations. It is also important to keep in close touch with our existing communities and so I plan to continue regular visits to our National Committees and Supportive Members. As previously mentioned, we also have a Supportive Membership program for companies that I would like to see even more leading companies join. Finally, we have an Affiliate Membership program for countries with developing economies and it would be great to enlarge our network in this area.

I have talked a lot about the CIE's role as the global authority in light and lighting and the importance of keeping the organization well-networked to other organizations. In this context, we're working to make the best use of our existing partnership agreements, and we hope to enlarge our network even more, and perhaps also formalize relations to our stakeholders through additional agreements with relevant international organizations.

Furthermore, we know that CIE Symposia, CIE Tutorials and CIE Workshops are top-quality events highly appreciated in the light and lighting community. So I am looking forward to working with the CIE Divisions to run a series of thematically focused CIE events in the future.

Our free webinars have gained popularity, and we are planning to continue offering them as much as we can.

And last but not least, I will do my best to support what I feel so many people value greatly about the CIE – our culture that combines professionalism and high-quality work on the one side with a welcoming and supportive community on the other side.

LED professional: **Thank you so much for this exclusive and extensive interview. It was a pleasure talking with you.**

Dr. Diana Wernisch: Thank you very much. ■

For additional information, please visit https://cie.co.at

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Further CIE Publications in LpR:

- **Bergen, Tony**, Vice-President Technical of CIE, "Global Leadership in Lighting – CIE's Role in Driving Technology", LpR105, Sept/Oct 2024, p20-24.
- **Hao, Luoxi** Prof. Dr., Vice-President Education at CIE, "From Research to Impact: CIE's Role in Global Lighting Education", LpR108, Mar/Apr 2025, p20-28.
- **Thorns, Peter**, Vice-President Standards at CIE, "The Beacon of Standards – Insights from CIE's VP on the Evolution of Lighting Technology & Design", LpR104, July/Aug 2024, p21-25.
- **Veitch, Jennifer** Dr., President of CIE, "Lighting the Way Forward – A Comprehensive Look at the CIE's Strategic Vision for the Future of Lighting", LpR103, May/June 2024, p20-24.

Address Delivered by Dr. Diana Wernisch, Secretary General of the International Commission on Illumination (CIE), at the CIE Midterm Meeting, Vienna, July 2025.

CIE Midterm Meeting Vienna 2025 Report – Scientific and Technical Highlights of CIE 2025 – Future Trends and Developments

Reported by Tony Bergen, CIE Vice-President Technical and Diana Wernisch, CIE Secretary General with support from the CIE Governing Board and Technical Management Board members.

The CIE – International Commission on Illumination is a scientific organization and an international standardization body registered with its headquarters in Vienna, Austria. In July 2025, the global community gathered in Vienna for one of the CIE's plenary meetings – the CIE Midterm Meeting Vienna 2025 ("CIE 2025").

CIE 2025 proved to be a milestone for integrating developments of the past years and setting the groundwork for the continued global leadership role of the CIE. The event was a resounding success, with 430 persons from 40 countries or territories attending the scientific conference (which saw 87 oral presentations and 168 poster presentations that all underwent a double-blind scientific review) and 310 persons (of whom 240 were on-site) participating in the CIE's Division and Technical Committee (TC) Meetings program where the current and future scientific work of the CIE was discussed.

The unique role of the CIE attracts a varied audience – a mixture of experts from academia, industry, national metrology institutes, standardization bodies, Masters and PhD students as well as architects, lighting designers, engineers and lighting practitioners, and governmental and policy-representatives. This diverse audience also makes it attractive for sponsors and exhibitors, with a wide variety of innovative products and equipment on display.

CIE plenary conferences are held every two years, and because of the CIE's leading role are a place for our partner organizations and stakeholders to come together and integrate their work under the umbrella of the CIE. Not only were high-level delegates with special interest from several countries present (Oman, Algeria, Czech Republic) but also organizations like LUCI (Lighting Urban Communities International), ISO TC-274, the International Color Consortium (ICC), Dark Sky, the European Patent Office, and many more.

Here are some scientific and technical highlights insights from this year's CIE 2025 Scientific Conference (7-9 July, 2025) and the Division and TC Meetings (10-11 July, 2025).

Key Themes:

- **Integrative lighting:** There were a large number of papers on light and health. One of the keynote presentations highlighted how light impacts our physiology, including our circadian rhythms and hormone secretion, and how NASA has applied the principles we have learnt to change the lighting on board the International Space Station. The award for Best Paper went to a paper studying the effect of neuropsin as well as melanopsin photoreception on human circadian biology and light-dependent physiology.
- **Light pollution:** The effects of light pollution continues to be an important topic. The first keynote speaker gave an inspiring presentation on how the night sky view that our ancestors enjoyed is becoming less accessible. There was a workshop on the effect of electric light at night on wildlife and insects, in particular, during the conference, as well as a discussion meeting that brought together several lines of work on light pollution within the CIE during the Division and Technical Committee meetings. Note that (at the time of writing) CIE will soon publish a Position Statement on Obtrusive Light and Light Pollution, and we are in the process of establishing a Research Forum on Light Pollution.
- **Public lighting for safety and security:** There were multiple oral presentation sessions, many posters, and a workshop on aspects of public area

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lighting and lighting of roads for motor and pedestrian traffic. Speakers highlighted the urgent need to revise CIE 115:2010 Lighting of roads for motor and pedestrian traffic, 2nd Edition.

- **The dichotomy of anthropogenic light at night:** The need to get the balance right between public area and road lighting on the one hand and the need to protect our ecosystems at night on the other hand was highlighted time and again, both in the formal scientific program and in the many private conversations and discussions.
- **Daylighting and energy efficiency:** The smart and efficient use of daylight was a common theme, along with a need for new daylight metrics. This needs to be balanced with the need to minimize the effects of glare, and to consider the importance of the view out of windows from interior environments.
- **Cone fundamentals and color matching of displays:** There is increasing recognition that the CIE 1931 color matching functions are problematic for high dynamic range (HDR) and wide color gamut displays. There was a workshop on personal color management for display devices and consumer products and the need for standardization in this area.
- **HDR imaging and glare:** High dynamic range imaging for assessment of glare and obtrusive light was an important topic as well as the theme of a workshop. Advances in HDR imaging and challenges of application to real-world applications were discussed.
- **Virtual reality and augmented reality:** The application of virtual reality and simulation to tackle more extensive and specific experimental conditions was subject of an oral presentation session as well as a number of posters and is an emerging topic that is becoming more important.
- **Artificial intelligence and machine learning:** There was a keynote presentation on the development of artificial intelligence and application to color measurement. Use of artificial intelligence in the evaluation of research results was also a common theme among a variety of research topics. Measurement equipment that uses machine learning to produce synthesized measurement results was subject of a Division 2 discussion meeting during the Division and Technical Committee meetings.
- **New calibration sources:** There are continuing attempts to use LED calibration sources to replace the traditional quartz tungsten halogen lamp-based sources, and to extend the range of such sources into the UV and NIR domains.

Key Groups of Participants:

- **The CIE global network:** The conference was a perfect melting pot of people with 430 people attending from all around the world and covering a huge range of expertise in all aspects of light and lighting, color and vision, photobiology, image technology, and metrology. Over 90% of survey respondents rated the conference as “good” or “excellent”.
- **Young researchers:** CIE continues to celebrate, encourage and include young and emerging researchers. On the evening after the first day of the conference, a student networking event was held in which students were grouped with leaders in the organization for an informal chat to get a feel for how the CIE works and as a means to make important connections. There was also an award given for the Best Student Paper at the closing ceremony.
- **Education community:** Although there have been many education-oriented initiatives in the past, CIE now has a dedicated Vice-President Education. In addition to the student networking event mentioned earlier, there was a dedicated workshop on Academic & Professional Lighting Education held as part of the conference program.

As Chair of the International Scientific Programming Committee (ISPC), Tony Bergen, Vice-President Technical of the CIE, was extremely pleased with the high-quality scientific content of the conference. He has received so many positive comments personally and seen many LinkedIn posts where people have said how much they got out of the conference and especially the three keynote speakers. It was a huge effort by the ISPC members, and he sincerely thanks each and every one of them, as well as the additional people who reviewed the paper submissions, along with the CIE Central Bureau staff for their amazing organizational effort bringing the conference together.

Outlook

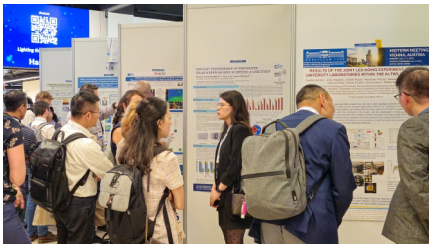
The papers submitted to the CIE 2025 Scientific Conference will be published in the CIE’s Publication Series *Proceedings of the CIE (International Commission on Illumination)*, ISSN no. 3061-015X (print), 3061-0168 (online). The publication is expected for autumn 2025 and will be available in the CIE webshop (67% discount for CIE National Committee members), partially open access.

Register for alerts and stay tuned for how the latest research and developments will be taken up the future work programs of the CIE: https://cie.co.at/about-cie/newsletter.

Did you miss CIE 2025?
Want to have a say in topics that require models, consolidated knowledge or regulatory and standardization work? Let our Vice-President Technical **Tony Bergen** know and write to ciecb@cie.co.at.

Are you an expert in a specific topic, not yet a member or working with the CIE but want to follow the work of a specific CIE Division? You can become a Division Associate, free of charge – contact the **CIE Central Bureau** at ciecb@cie.co.at.

Pre-registrations to receive updates (call for papers, etc.) for CIE 2027, the 31st Quadrennial Session of the CIE which will take place July 9-17, 2027 are already open: https://cie.co.at/news/31st-quadrennial-session-cie-nanjing-china. ■



Conference, exhibition, and gala evening at the CIE 2025 in Vienna.

LightingEurope Urges EU Rules for Artificial Light at Night

LightingEurope is urging the European Commission to adopt uniform rules regarding Artificial Light at Night (ALAN) to address its environmental and societal impact, as outlined in a recent position paper which is available on the LightingEurope website. The topic of ALAN has sparked intense debate over the past years, highlighting the need for modern lighting systems that prioritize both visual and safety needs for humans and environmental protection.

Importance of Well-Designed Lighting

High-quality lighting installations and intelligent control systems are crucial for creating safe and comfortable night-time environments. While the primary goal is to serve human needs, there must also be consideration for effects on the natural environment including fauna and flora as well as the effects of obstructive lighting, sky glow and light nuisance. Achieving an effective balance between user needs and ecological concerns is key.

Challenges with Outdated Infrastructure

Despite rapid innovation, much of Europe's outdoor lighting remains outdated and lacking in energy efficiency and ecological awareness. For instance, many streetlights can operate for decades, meaning existing installations often do not reflect the latest technological advancements or environmental standards. Upgrading these systems is vital.

Fragmented Regulatory Landscape

Standards and regulations for outdoor lighting have evolved to include environmental considerations, but the regulatory situation is inconsistent across the EU. Some regions, such as parts of Spain and Italy, use varying metrics and local laws, resulting in a disjointed framework where cities even introduce their own specific rules. LightingEurope's position paper calls for harmonization -so requirements for ALAN are clear, balanced, and effectively implemented throughout every Member State in the EU.

LightingEurope four guiding principles on ALAN

LightingEurope outlines four guiding principles to mitigate the adverse effects of ALAN:

- All light should have a clear purpose.
- Light is directed only to where it's needed.
- Light is not brighter than necessary.
- Light is adapted to suit the task activities or turned off when not required.

These principles reflect the capabilities of modern lighting systems of mitigating the adverse effects of ALAN by utilizing modern optics, controls, and color tunability. Additionally, remote management and controls provide municipalities and end-users with the options of adapting light levels according to local curfews or other public requirements. However, lighting systems that include the right features to mitigate the negative ALAN effects, still must be installed in the right way according to the manufacturer's guidelines and operated in the correct way. This "separation of responsibilities" remains essential also for state-of-the-art lighting products.

Importance of renovation and public procurement

Renovating outdoor public and commercial lighting should support the EU's internal market and help to meet environmental and energy goals through harmonized legislation. The European Commission has suggested that public procurement could be utilized to steer innovation and sustainability. Therefore, LightingEurope proposes that tenders for public and commercial outdoor lighting should mandate adaptability in light output depending on factors such as time, ambient light level, or activities, among others. Luminaires should have the technical capability of being dimmable between 10% and 50% output level according to the application and, when relevant, to the environmental zone.

Aligning with existing standards

Lighting should also be designed to light the space for safety, function and comfort with minimal effect on surrounding areas and with consideration of the environmental zone. LightingEurope recommends to particularly limit the upward light ratio according to the latest standard for lighting of outdoor workplaces - EN:12464-2.

Adapted spectrum and installation

Additionally, the spectrum of the light source should be considered depending on environmental requirements. This should balance the needs of people and nature based on existing populations and activities. Changes throughout the day and year should also be considered, and luminaires with adaptable spectra and brightness should be used where beneficial.

Ultimately, light installations should be designed by competent designers and installations should be checked against design parameters over the lifetime of the installation.

The lighting industry has the technology, knowledge, and vision. What it now needs is regulatory coherence and collective ambition across Europe. ■

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The topic of Artificial Light at Night was also an important focus at the LightingEurope Summit 2025, led by Secretary General Elena Scaroni.

The Heartbeat of Smart Cities: What 6,000 Projects Reveal About Urban Life Dr. Beverly Pasian, University of Applied Sciences Utrecht (HU)

Dr. Beverly Pasian:
"Every lighting project is also a social project. It tells us what kind of future a city imagines."

In this exclusive interview with Dr. Beverly Pasian, a leading voice in project management and smart city research, we uncover how lighting shapes the future of urban living. Drawing on insights from more than 6,000 smart city projects worldwide, she reveals the recurring "heartbeat" of urban priorities—where safety, sustainability, and social well-being converge. From overlooked themes like ageing and gender equity to lighting's symbolic power, Dr. Pasian shares why human-centric innovation must guide the next generation of smart cities.

www.hu.nl/onderzoek/onderzoekers/beverly-pasian

LED professional: Could you tell us a bit about your professional journey and how it led you to pursue a doctorate in business administration?

Dr. Beverly Pasian: I started my career as a project manager working in the Canadian federal government. This was in the early days of the Web. Public affairs officers at both Environment Canada and the Department of National Defense had started using websites as tools to communicate with the public. It was this educational perspective that influenced me enormously, leading to my first master's (in online & distance education) at The Open University (UK).

The management of these projects appealed to me more than the pedagogical issues behind them. Focusing on implementation gave me a way into a professional doctorate in project management. And I was fortunate to find an academic home at the University of Technology, Sydney. Twenty years ago, doctoral work in project management was easily found in engineering faculties, but candidates focusing on social science issues weren't accepted. UTS was a pioneer in this regard and was happy to support my research on educational projects.

Examining the project management capabilities within teaching and learning centers at universities was my focus. They were (and remain) a terrific domain for innovative, dynamic and reliable project management activity. Theoretically, the notion of 'reliability' was most associated with the concept of 'project management maturity,' along with definability, repeatability and predictability. Applications were easily found in manufacturing environments and software projects, but rarely outside these domains. I showed the inherent limitations of this concept and minimized its applicability in project management. This was helpful as it laid the groundwork for other challenges to what had been a dominating managerial principle.

Achieving this milestone was satisfying, but not as much as I had expected. Despite coming from practice, my work took on an especially strong theoretical orientation and did not ultimately lay the foundation of a robust research career. After a few years, my academic career and enthusiasm slowed down. I had had some success with books and professional association leadership, but I needed more out of my research work, so I went back to school.

In 2018, I enrolled at SKEMA Business School (France) to complete an MBA. When the time came to do a thesis, I realized that a second doctorate would have greater meaning to me and possible impact to others than a master's thesis. So I converted my enrolment to a double degree (MBA-DBA) focusing on project management.

It was also during this time that I attended a workshop in Berlin hosted by the International Project Management Association. I had volunteered at IPMA for many years and knew they were expanding their leadership on key topics. In the fall of 2018, that topic was smart cities. All day I heard about creative, socially responsible and innovative projects—all in support of the United Nations SDG on Sustainable Cities & Communities—that were missing from the professional landscape I was in. I was hooked after that day.

LED professional: What inspired you to focus on smart cities as the core of your doctoral research?

Dr. Beverly Pasian: A few factors combined to make smart cities an exciting topic. The first being the cities that I'd called home. I've had the great privilege of living in cities that are regularly listed highly in quality rankings. In the 10 years immediately before my smart city research, I had lived in Vancouver and Toronto, from my home country, Sydney, Australia, and my current home city of Utrecht, the best City in the Netherlands!

During my MBA studies at SKEMA, I had the opportunity to work with one of the pioneers of project management research as my academic supervisor, Dr. Aaron Shenhar. I had met him years before when he received the IPMA Research Achievement Award and, funnily enough, bought his 'Reinventing Project Management' book when I was accepted to my first doctoral program. Thankfully, he remembered me and was similarly intrigued by researching smart cities. We met and agreed to work together.

This explanation might be a little boring for your readers. The fact is, I used my personal experiences and interests to chart this path. I would recommend this to anyone doing advanced research. Find something that resonates with you

as a person. Or as a citizen. You will never go wrong and will be motivated for years.

LED professional: How has your international experience shaped your view on urban innovation and project management?

Dr. Beverly Pasian: I've had the good fortune to travel extensively for work and school and have lived in some fantastic cities in the last 30 years – Toronto, Vancouver, Sydney, Ottawa, Florence and now Utrecht. My professional life—working with IEEE and IPMA—has also filled my passport with visits and collaborations in many of the world's great cities.

Beyond that, I now have this enormous project collection started in my doctorate. More than 6100 official smart city projects from around the world reflect an amazing collection of priorities by individual cities. They offer specific lenses through which to see how citizens in future versions of those cities will live.

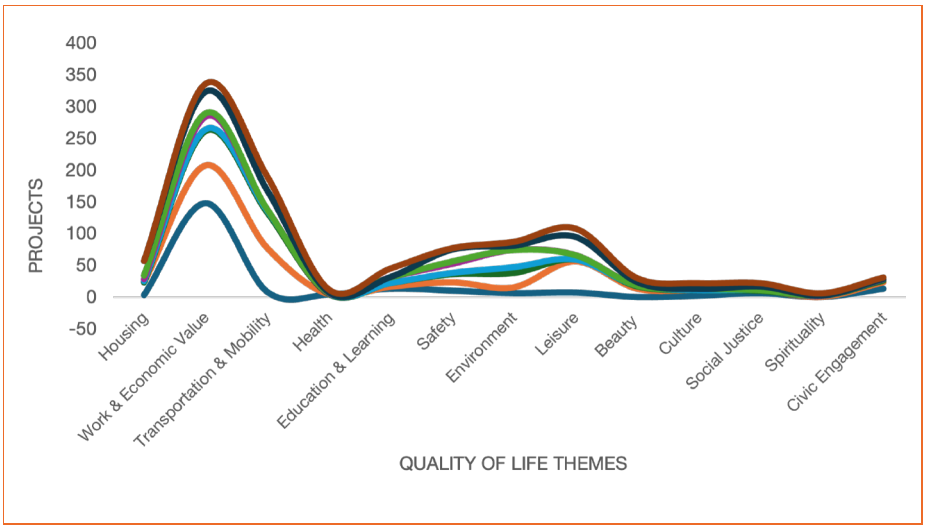
What I mean by that is that project collections very clearly reflect government priorities, and, through those choices, you can see how 'city hall' (in the aggregate) imagines the future version of a city. Sometimes those views reflect social interests, sometimes not. Business interests and broad public utilities (e.g. expansive WIFI installations) are emphasized. But sometimes there are cities where the projects reflect national characteristics that are typically associated with that place. The City of Calgary, for example, emphasizes social justice, a priority often associated with Canada. The collection from Australia emphasized beautification and leisure projects, characteristics often associated with that wonderful country.

Given my familiarity with those places, the profile created by those projects rings true for me. And the consistency of the 'heartbeat' distribution raises the possibility that other locations can be reliably understood through a smart city project lens. This gives hope and an international perspective that I wouldn't have otherwise had.

LED professional: Can you summarize your thesis in a few sentences?

Dr. Beverly Pasian: I studied the role of projects in contributing to the quality of life in smart cities. Using a clear and simple definition of a smart city, I applied a model of 13 themes against 5000 official smart city projects. It repeatedly showed the same distribution of projects from collections around the world. Its appearance resembles the 'lub dub' of a human heartbeat... hence its name.

At first, I was disappointed by the results. They seemed to indicate very low attention to those projects that contribute to the quality of life. But Aaron turned me around. The more foundational projects (housing → environment) were necessary for the more exciting projects to occur. It is a good news story that shows much potential for smart city planning.



The Heartbeat: Project distribution in smart cities. Pasian, PhD thesis, SKEMA, 2024.

LED professional: Could you tell us about your research methods?

Dr. Beverly Pasian: I love talking about this! My original research design was a multiple case study where I was to examine individual cities selected for their quality-of-life commitment. The plan was for me to visit these cities, conduct interviews and gather project details. I likely would have used videos, photographs, field notes and official city documents, including archives, but then the pandemic happened, and my plans needed to be adjusted. I made two significant changes in my research design.

The first was to travel the digital highway as much as possible. Interviews would proceed but would be conducted virtually. But because of everyone's extraordinarily busy schedules during that time, I sought complementary material. The people I spoke to were city representatives who were responsible for explaining and promoting their smart city strategies. I was the only one of many they would speak to during their jobs. Finding conference presentations, articles, and other interviews they had recently given was easy and proved enormously complementary to the interviews. If I'm being honest, I don't know if I would have thought to look at alternative sources, but the pressure of the pandemic helped me.

The second change concerned an unplanned data collection effort. I was feeling a little insecure about not visiting my chosen cities, and while I was pleased with the quality of my city contacts, I wanted to do more. I wanted to be more creative in using information in the public domain. So I turned to the lists of various city rankings (e.g. Global Livability Index, the Smart City Index, Mercer Quality-of-living Ranking) and reconciled their results. I ended up with a list of more than 100 cities and started working on it! One by one, I went to the official city websites and looked for project data. It was here that I started seeing some significant differences.

The leading cities had comprehensive information concerning their strategies, consultation efforts and project information. All of this was always available in English. Other cities further down on the list had good information, but not always accessible to a broader audience. Public consultations, vast project implemen-

tation details and scheduling were also posted. These cities were taking their information-sharing responsibilities seriously.

Looking back at my research proposal, I'm surprised I hadn't considered using the ranking list to associate it with the information. The case studies would have been sufficient, but the project data set completely opened up my research. I also use it as an example with my research method students. I encourage them to be creative and look beyond conventional data sources.

LED professional: What were the most surprising or unexpected findings?

Dr. Beverly Pasian: I'm not sure where to begin with this answer! This research was and remains a labor of love. I'm regularly surprised and delighted by the perspective it has brought me perspective on urban living. But to be more specific, beyond the heartbeat model, I will mention a few.

Housing and health-related projects were given little attention in many highly ranked cities. When I asked for explanations, respondents spoke of jurisdictional boundaries and policies determined by other government offices. Health policies often reflected federal policy, as did housing decisions. Individual cities often couldn't meet the needs of their residents and visitors because of this. In fairness, the city representatives I spoke to were not happy.

Another surprise concerned the lack of attention to very basic human dimensions. I'll mention two. We are currently living in the decade declared by the World Health Organization as the "decade of healthy ageing." One of its key goals is to create an age-friendly environment in cities, communities, and the services they provide. One portion of my data set is the 1024 smart city projects of my eight case study cities. Twelve projects gave specific attention to senior or elderly citizens. For this article, I looked at the broader data set – more than 6100 projects. Of those, 38 mentioned elderly citizens. (And I'd like to gently add a related observation... I searched the led-professional.com site using the same terms. With 'elderly,' 14 results were generated...the most recent being from 2021.)

Perhaps this is a problem of basic communication. The publicly available project details might simply not have included vocabulary associated with senior or elderly citizens. At worst, there is an enormous segment of our urban society that is not being considered as the city grows around them. That is a nightmare scenario.

Similarly, anyone who studies urban planning knows that different genders navigate cities differently. There are many reasons for this that I won't go into here. But after conducting the quality-of-life thematic analysis for my research, I remember thinking... What other conclusions can I draw? Using the very basic (and exclusionary) terms of 'male' and 'female,' my initial dataset provided unsettling insights. And for this piece, I revisited my larger collection and searched the words: female, women and woman. Only 63 projects were highlighted.

And, with respect, I'd like to share search results from the led-professional.com site using 'woman,' 'female,' and 'women.' In total... 44 results. However, when I looked at the latest issue of LED Professional (July-Aug 2025), there is a terrific article on the responsibilities of sustainable public lighting. Weninger, Ascher and Dick specifically advocate paying attention to the requirements of gender-specific perceptions of safety. This is exactly what I'm talking about.

Again, it is possible that city officials do not incorporate gender-specific language into their project decisions in their public descriptions. And perhaps with awareness raised through publications such as LED professional Review, that could change. But... Is it possible that, at the most basic level, projects are being conceived and implemented in ways that will not accommodate different gender needs in our future cities?

The last item I'd like to focus on is spirituality... It's one of the 13 themes in my quality-of-life model. And my comments have nothing to do with any particular religion, although I do bring up the Roman Catholic Church as an example. It concerns stakeholder management.

By way of background, a quick personal anecdote. I attend two of the notable churches in Utrecht... St. Catherine's Cathedral and St. Augustine. One Monday evening, as I closed the cathedral, my mind wandered to my smart city research. It occurred to me that if the population growth and immigration patterns were in any way accurate, cities should expect greater attendance at churches, mosques, synagogues or other places of worship. So that same night, I quickly looked up some basic facts. According to the University of Notre Dame (USA), faith-based organizations such as the Roman Catholic Church are amongst the world's largest non-governmental landowners, with significant influence in the urban landscape. I added 'spirituality' to my model the next day.

Of course, this meant revisiting my project list. There were only a few initial examples, such as cemetery management, which seemed limited at first glance. Further research revealed inspiring initiatives, such as the national 'We Are Green Churches' project in the Netherlands (groenekerken.nl), which shows how faith communities can actively support sustainability goals. That team has done an amazing job in engaging communities to sensitively and purposefully consider the built environment in which church properties function and make changes, as necessary.

Fortunately, engagement with faith-based communities has grown, but there is still significant potential for growth in engineering communities. An example for your readership... The Evangelical Church of the Augsburg Confession in Austria aims to establish a network of solar power systems on church balconies, ultimately creating the largest balcony power system in Austria. The economic advantages are immediately clear, but as a social scientist, I applaud the cultural and social cohesion such a project creates.

LED professional: In your view, what is the main contribution of this work?

Dr. Beverly Pasian: That's a hard question to answer. If I had to pick one thing, I would point to the recurring heartbeat distribution of the projects. They demonstrate the relevance and impact of specific, measurable quality of life dimensions. As I said in my thesis, assessing progress against those themes to mark the evolution of a city is possible. But that is an abstraction in many ways. In more concrete terms, the projects associated with those themes could be

valorized with the results applied to all sorts of city planning.

LED professional: Your work investigates the intersection of smart cities and urban lighting – why is lighting a powerful lens through which to view urban transformation?

Dr. Beverly Pasian: In preparing for this interview, I looked through the various issues of LED professional Review. My answers are consistent with many of the issues raised by other contributors. Perhaps coming from a social scientist, they will offer some reassurance. Perhaps even introduce or strengthen opportunities for transdisciplinary research.

Lighting is a physical manifestation of change. Installations are tangible, visible aspects of urban development and indicators of urban priorities. Changes in lighting infrastructure—from the replacement of older technologies (e.g., high-pressure sodium lamps) with LEDs to the implementation of smart, dynamic systems —directly reflect broader urban priorities and transformations. Analyzing these changes reveals shifts in energy efficiency goals, technological advancements, and approaches to public safety and urban aesthetics.

Lighting has a direct and immediate impact on social life and safety. Improved lighting can enhance visibility, deter crime, and create more welcoming public spaces. In contrast, inadequate lighting can have the opposite effect. Analyzing lighting projects (or their absence!), therefore, provides insights into how urban planning addresses issues of safety, accessibility, and social equity. The European Charter for Equality of Women and Men in City Life (topics) specifically mentions street lighting as a factor influencing women's safety and security.

Lighting choices are reflections of urban identity and can contribute to the overall aesthetic and identity of a city. The design and implementation of lighting schemes can reflect a city's cultural values, history, architectural style, and aspirations for the future. A great example from Utrecht is 'I light you' – an exhibition that showcases the work of national and international light artists in and around the central train station (January–February, 2026) (ilightu.nl). It's been running for a few years and is such a fun demonstration of how a hybrid of technology and art can serve a community. Analyzing these lighting projects offers a window into how cities seek to present themselves to residents and visitors alike.

Lighting projects are not merely about illuminating streets and buildings; they are integral components of urban development, reflecting broader societal values, technological advancements, and aspirations for the future. Analyzing these projects provides a multifaceted perspective on urban transformation, revealing insights into a city's priorities, its social fabric, and its evolving identity.

LED professional: What is an example of where a smart lighting initiative led to broader innovation in city planning?

Dr. Beverly Pasian: It's not possible to limit myself to only one example. Here are a few from around the city of Antwerp, which has its 'Antwerp Light Plan' to improve the basic lighting of streets and neighborhoods, structured lighting and mood lighting. Bologna has their 'enlightenme-project.eu,' a multifaceted project to understand how indoor and outdoor lighting affects health and well-being. The elderly population is a particular focus for them. In the US, several cities, including Philadelphia, Dallas and Chicago, focused on replacing traditional sodium streetlights on a huge scale. Chicago, for example, had its 'Smart Lighting Project' to modernize outdoor lighting and install wireless lighting management. It was an enormous project that replaced over 270,000 outdated sodium lights with LED lights. Imagine what that did to those neighborhoods!

But if you would indulge me, I'd like to briefly mention on one area of innovation…how Lighting can contribute to innovation in transportation and mobility. With so many cities moving toward a 15-minute model, this combination needs attention. What can be done?

Let me give you a concrete examples from the Netherlands.

For years, the Dutch cycling community has lead the way in innovation and collaboration. The city of Zoetermeer specifically improved its lighting across the network in order to improve social safety and night time cycling. And this was years ago...long before 'smart cities' was a popularized term. More generally, bicycle innovation labs are all over the country continually working with various domestic partners to push the envelope. Andn then organizations such as the Dutch Cycling Embassy (dutchcycling.nl) make a point of sharing their insights globally.

And of course, lighting enhances road safety through improved visibility. Smart lighting systems can dynamically adjust lighting levels based on real-time conditions, such as weather, traffic volume, and time of day. This can improve visibility for drivers, cyclists, and pedestrians, reducing the risk of accidents, especially in low-light or adverse weather conditions. It also provides insight into how adaptive lighting can be optimized to improve visibility for various user groups. Targeted illumination can highlight pedestrian crossings, intersections, and other high-risk areas, improving safety for vulnerable road users and reducing accidents involving pedestrians and cyclists.

Optimize traffic management with adaptive lighting and integration with traffic signals. Smart Lighting can be used to optimize traffic flow by adjusting lighting levels based on traffic volume and congestion. For example, brighter lighting can be used in congested areas to improve visibility and reduce the risk of accidents. In contrast, dimmer lighting can be used in less congested areas to save energy. This can lead to smoother traffic flow and reduced congestion. Smart lighting can be integrated with traffic signals to provide drivers with better information about traffic conditions and optimize signal timing. This can improve traffic efficiency and reduce delays.

Make autonomous driving safer. Improve localization and navigation by using smart lighting systems that have precise information about road geometry, lane markings, and vehicle-to-infrastructure communication features. This can improve the safety and efficiency of autonomous driving.

You only asked for one example…so I'll stop there!

LED professional: What are the main barriers cities face when implementing smart lighting?

Dr. Beverly Pasian: Several barriers were identified in my research, starting with high costs. The implementation of smart lighting systems requires significant upfront investment in infrastructure, technology, and installation. This can be a major obstacle, especially for cities with limited budgets. The city of Dortmund, for example, addressed the high budget it needed for transportation projects, which often include lighting upgrades.

Smart lighting systems are vulnerable to cyberattacks, requiring robust cybersecurity measures to protect against data breaches and system disruptions. My Bilbao case study highlighted the importance of cybersecurity for citizens and the need for defense systems.

Public acceptance of smart lighting systems can be a challenge, particularly if there are concerns about privacy or surveillance. For example, the city of Vilnius case study included a "Happiness Project" using facial recognition, highlighting potential privacy concerns. You can only imagine the planning conversations!

Smart lighting systems collect data, raising concerns about data security, privacy, and potential misuse. Robust security measures are essential to protect sensitive information and ensure public trust. The ethical implications of data collection need careful consideration.

It's important to note that these barriers are interconnected and can exacerbate each other. For example, high costs can limit the availability of skilled personnel and robust data management systems, while a lack of public acceptance can hinder securing funding for projects. Addressing these barriers requires a holistic approach that considers the technical, financial, social, and political aspects of smart lighting implementation.

Zwolle, Hanzeboog: Built in 2010, the Hanzeboog is a rail and cycle bridge spanning 925 metres across the IJssel River in Zwolle. Its striking color and shape makes it not just photogenic but also mediagenic—having become an icon for the city and the subject of a postage stamp. Credits to the Duch Cycling Embassy.

LED professional: In your view, how can lighting be used not only functionally but also emotionally or symbolically to shape citizen experience in smart cities? Are there any unexpected roles or consequences of lighting systems beyond safety and efficiency, such as community engagement, identity or equity?

Dr. Beverly Pasian: This is a hugely important question. To answer it, I will also address a theme from an earlier question. One that concerns the potential emotional or symbolic nature of lighting. As I was doing my PhD, I became aware of various international accords meant to protect the rights of people living in cities. They include the European Charter for Equality of Women and Men in Local Life, the Global Charter of Human Rights in the City and a Framework for Reinforcing Human Rights in the City. What some of your readers may not know is that lighting is identified in two of them as a specific right worth protecting. One thing that is guaranteed to be an emotional trigger is the perceived or actual threat to someone's rights. We certainly saw a lot of that during the pandemic.

But protection is only one benefit of these agreements.

By articulating specifics and giving vocabulary to the abstractions of city life, these agreements create common ground. What life should be or what a citizen should have is no longer up for debate. And collectively, lighting professionals can move on to the next question… What responsibilities do we have to protect those rights? And by answering this question, lighting professionals become advocates. They become protectors of rights codified by civic leaders, in addition to contributors to safety and efficient city operations. By pointing specifically to these accords, conversations open to greater project ideas.

The European Charter for Equality of Women and Men in Local Life, for example, specifically identifies street lighting as part of the local environment that could protect women. And, despite being from 2006, attention toward

women's interests is rarely articulated in smart city projects. This could easily change if lighting professionals address it in their projects. Such advocacy would open the door to new relationships. Women in Lighting (womeninlighting.com) and Women Light the World (womenlighttheworld.org) are two examples. Imagine how your readership would be inspired by hearing from such groups!

LED professional: To what extent did artificial intelligence play a role in the case studies or data analysis?

Dr. Beverly Pasian: Artificial intelligence played a significant, albeit indirect, role in this research. When I conducted my qualitative data analysis, I used MAXQDA software. While MAXQDA itself isn't an AI, it's a sophisticated qualitative data analysis tool that incorporates various features to assist researchers in managing, coding, and analyzing large datasets. These features aided in the organization and interpretation of the qualitative data I gathered from interviews, documents, and social media.

LED professional: Do you see AI as a future enabler for managing complex urban projects like smart lighting infrastructure?

Dr. Beverly Pasian: I didn't look at this particular issue during my research, but I took a second look for this question. My answers are more extrapolations. Yes, AI has significant potential to be a future enabler for managing complex urban projects like smart lighting infrastructure. There are several ways this could happen.

Let's start with optimized design and planning. AI can analyze vast datasets (weather patterns, traffic flow, energy consumption, etc.) to predict the optimal placement and configuration of lighting infrastructure, maximizing efficiency and minimizing energy waste. AI-powered simulations could then model different lighting scenarios, allowing planners to test various designs and configurations before implementation, identifying potential issues and optimizing performance. This predictive capability could lead to more effective and cost-efficient designs.

Real-time monitoring, control and risk management seem obvious possibilities. AI-powered systems can monitor the performance of lighting infrastructure in real-time, detecting faults, optimizing energy consumption, and adapting to changing conditions. This allows for proactive maintenance and prevents disruptions. Emergency response should also be at the top of the list. AI can assist in emergency response by automatically detecting and reporting outages or malfunctions, enabling faster response times.

Citizen engagement could be enhanced. AI could personalize lighting experiences based on individual preferences and needs, improving user satisfaction and supporting interactive feedback. This could also increase transparency and improve public acceptance. By directly experiencing the benefits, citizens might be willing to discuss further possibilities.

Of course, there are assumptions and potential issues in realizing these possibilities. AI relies on high-quality data and computational resources that small to medium-sized cities may not have. The use of AI in urban projects will always raise ethical concerns about privacy and surveillance. The enormity and complexity of integrating AI systems will be made worse by skills gaps in multiple roles.

LED professional: How can AI support more human-centered outcomes in smart cities and improve the quality of life?

Dr. Beverly Pasian: My research offered contrasting perspectives on how AI supports human-centered outcomes in smart cities. There were several examples of projects that, while not always explicitly mentioning AI, utilize AI-supported technologies to achieve their goals.

Specifically, improvements in safety through smart lighting systems in Antwerp, Mons, and Berlin adapt lighting levels based on occupancy and pedestrian/-cyclist detection. The improved safety is achieved by optimizing lighting for different situations and illuminating pedestrians and cyclists in a targeted manner. The City of Dortmund (Germany) has been piloting this for the last five years in an innovative infrastructure project that enhances cycling comfort and appeal. Special sensors at traffic lights automatically detect approaching cyclists and request a green light about 35 meters before the stop light. Between 2020-2025, 37 systems will be retrofitted.

Responsible implementation is crucial, and AI could contribute in many ways. Adaptive lighting could allow AI to analyze real-time data from various sources (cameras, sensors, etc.) to adjust lighting levels dynamically. This means brighter illumination in high-traffic areas or when suspicious activity is detected, improving safety and deterring crime. This can include targeted illumination of pedestrian crossings or areas with higher crime rates.

Energy efficiency and sustainability can be seen in smart dimming and scheduling. AI can optimize lighting based on occupancy, time of day, and weather conditions, reducing energy consumption significantly by reflecting individual preferences.

Naturally, there are challenges. AI systems require data collection, raising

The city of Dortmund relies on innovative technologies to make cycling more convenient. Smart sensors record bicycle traffic and adjust traffic light green phases when needed, reducing the number of times cyclists have to stop at red lights—improving both comfort and the overall appeal of cycling.

concerns about citizen privacy. Robust anonymization and data security measures are essential. AI algorithms can reflect and amplify existing societal biases. Careful design and testing are needed to ensure fairness and equity. Public acceptance of AI-powered systems is crucial for successful implementation. Transparency and public engagement are essential.

AI integration with lighting projects holds immense potential for creating more human-centered smart cities. However, careful consideration of ethical implications, data privacy, and public acceptance is paramount to ensure that these technologies truly benefit all citizens.

LED professional: **What are three key messages for lighting professionals?**

Dr. Beverly Pasian: I've been asked a version of this question many times. And my answer is always the same. Remember that you are a citizen at the beginning and end of each day. What you do in between—as a lighting professional, an engineer or project manager—should support those interests.

Two…Thoroughly document the social impact of a proposed lighting project and then communicate communicate communicate the results. It's not enough that lighting professionals understand…key stakeholders need to know what's happening and who they can partner and progress with.

And the wheel does not need to be reinvented! A simple example… in December 2022, the United Nations High Commissioner for Refugees published 'Protection-Sensitive Access to Lighting' for its personnel and partners. In addition to reinforcing the right to lighting access as a key sustainable development goal, it details many principles, approaches and recommendations for achieving this. It's 40 pages from cover to cover, and balances inspiration and pragmatism. It, or something like it, should be on the desk of every lighting professional.

Three… Use your expertise to work with new stakeholders and organizations most directly embedded in cities. Two come to mind. The first…there are more than 450 universities of applied science (UAS) in Europe (more than 20 in Austria), mandated to innovate for the greatest societal impact and are eager to work with partners. Avans UAS in the Netherlands) recently finished its Smart Light Concepts project and published tremendous insights that would allow public lighting to save money, energy, and carbon. Eindhoven TU/E has its Lighting and IoT lab. I'm also excited to say that the Utrecht University of Applied Sciences Utrecht (my university!) has recently created a new team to focus on transportation and mobility in urban development. We are eager to explore lighting-related projects and would very much like to hear from possible collaborators.

The second is, more broadly, think tanks or advocacy groups that specifically look at the quality of life and cities. A few come to mind… The Resilient Cities Network (resilientcitiesnetwork.org), the Rainbow Cities Network (rainbowcities.com), and the Institute for Quality of Life (institute-ql.com). Each offer combines specific ideas, policy recommendations, and/or projects, ready for interpretation by lighting professionals.

LED professional: **Where do you see the greatest potential for innovation in smart lighting over the next 5 to 10 years?**

Dr. Beverly Pasian: More attention and ideas are needed on social innovation. Imagine if the pause button were hit today, amongst even a portion of the educational programs or engineering companies devoted to smart lighting. Imagine if that time was dedicated to actively working with universities, think tanks, and anyone else who can develop a civil society agenda for smart lighting. Find money – you probably don't need a lot – and implement it. Again, for this piece, I looked up examples and found many related to business models and technological advancements. Microfinancing is very well known. Medical drone delivery is increasingly used.

Digital identities for refugees help access aid. At a local level, repair cafés and cohousing are increasing. But where are the examples for smart lighting? The fact that few can be found tells me we haven't talked about it yet. Let's create as many opportunities as we can to do just that. Perhaps in future issues of this publication?

LED professional: **Thank you very much for taking the time for this exclusive interview.**

Dr. Beverly Pasian: My pleasure. ■

Beverly Pasian (MA, DPM, EMBA, PhD) is a senior researcher and joined the Process Innovation & Information Systems research group in 2025. She is part of the SMARCO project team, a project which the HU, in collaboration with 22 other European organizations, addresses the question of which skills professionals need to transition to greener and more smart digital communities. The goal is to train professionals to create the city of the future.

For over 20 years, Beverly has led, taught, and conducted research in the public sector worldwide. Her work focuses on project management, research methods and design, and smart city projects. She has authored dozens of courses, papers, books, and presentations, as well as master's degrees (in education and business administration), a doctorate in project management (2011), and a doctorate in business administration (2023).

She enjoys collaborating with city officials, project managers, and researchers to determine how projects can achieve a high quality of life. She chairs the IEEE's European Technology & Engineering Management Summit (etems.digital), is a member of IPMA's Smarter Urban Rural special interest group, and co-hosts the new podcast CitiesR4living.

Dr. Pasian's recent collaborations include:

- 'Citiesr4living' Podcast (co-host, IPMA)
- A City's Heartbeat: Project Contributions to Quality-of-life in smart cities (PhD Thesis, SKEMA University, 2024)
- Design, Methods & Practices for Research of Project Management (Taylor & Francis, London, 2023)
- Handbook of Responsible Project Management (De Gruyter-Brill, Berlin, 2022)

beverly.pasian@hu.nl
linkedin.com/in/beverlypasian
hu.nl/onderzoek/onderzoekers/beverly-pasian

Gaggione Drives Innovation Forward with New Optics Tailored for Urban and Smart Lighting

Gaggione

Gaggione, a leading innovator in high-performance optical solutions, recently made a strong impression at the Guangzhou International Lighting Exhibition (GILE) 2025, one of the world's premier lighting industry events. This exhibition marked the beginning of Gaggione's 2025 global trade show circuit, where the company demonstrated its expertise in custom optical design and cost-efficient standard solutions, ensuring the perfect balance of performance and value.

At its booth, Gaggione highlighted its cutting-edge optical technologies, featuring both bespoke optical systems and the latest additions to its standard optics portfolio. Key innovations included advancements in precision light control featuring patented RGBW color mixing zoom optic, efficiency optimization, new recycled materials and compact optical designs— reinforcing Gaggione's role as a trusted partner for high-end lighting applications.

Strategic Focus for 2025: Innovation & Global Engagement

With a strong emphasis on visibility and next-generation optical solutions, Gaggione is set to deepen its engagement with industry leaders across major markets. The company's participation in GILE 2025 underscores its commitment to pushing the boundaries of lighting technology while supporting clients with tailored, high-performance optics.

Next Stop: The Street & Area Lighting Conference (SALC) – USA

Gaggione's 2025 roadshow continues at the Street & Area Lighting Conference (SALC), where it will present its latest innovations for urban, architectural, and smart lighting applications. Industry professionals are invited to connect with Gaggione's team to explore next-gen optical solutions that enhance efficiency, durability, and design flexibility.

Gaggione: French Expertise in the Service of Precision Optics

Gaggione (**Figure 1**) is a French company located between Lyon and Geneva (Switzerland). Founded in 1948, it first made its name in plastic injection molding, before specializing, for over 30 years now, in the design and manufacturing of high-precision optical components. With a strong international focus, Gaggione conducts a significant portion of its business through exports and also operates a production site in Canada via its subsidiary, Quadratec.

With a team of around 100 employees, the company has invested heavily in skills development, relying on an expert R&D team and top-tier optical engineers. These investments also extend to its advanced technological equipment, including high-precision injection molding machines, machining tools, and state-of-the-art optical measurement systems.

Thanks to this extensive set of resources, Gaggione can support clients at every stage of their project, regardless of geographical location — from the initial optical study to component design and manufacturing. While historically focused on custom solutions, the company has recently expanded its offer with a standard range of efficient and cost-effective optical components.

Lenses, reflectors, collimators, and light guides — Gaggione meets the diverse needs of the lighting market by combining innovation with industrial excellence.

Gaggione's Technical Heritage: A Mark of Trust

From its early days, Gaggione has distinguished itself through its ability to design high-value-added optical components that meet stringent regulatory requirements. From urban lighting to medical optics, including specialized applications such as light obstruction, the company has established itself as a go-to-partner capable of tackling the most complex challenges.

This historical know-how has played a major role in building Gaggione's reputation and remains a key part of its brand identity. In the market and among its clients, the name "Gaggione" is instantly associated with technical components — whether very small or very large in size.

www.optic-gaggione.com

The Development of the Standard Range: A Strategic Response to Changes in the LED Lighting Market

Faced with competition and the rapid transformation of the LED lighting industry, Gaggione proactively launched its standard optics range as early as the 2000s, marking its entry into a new market segment.

While its custom solutions remained high performing, they no longer met all client demands or the growing constraints of technical specifications. The need for standard components quickly became evident. This strategic diversification enabled Gaggione to offer high-quality optical components for a broader range of applications, all while optimizing production efficiency and cost.

By betting on a demanding technical approach and maintaining close market awareness, Gaggione has confirmed its status as a leader in the optic sector. Refusing to rely solely on its high-end specialist reputation, the company continuously refines its strategy with one clear objective: delivering the optimal balance of performance, quality, and cost-effectiveness. A strategy that challenges conventional wisdom and strengthens its legitimacy in an increasingly global market.

Optical Performance that Stands Out

With proven experience in executing complex, high-tech custom projects, Gaggione has developed unmatched expertise in color mixing and high-intensity beams with ultra-low divergence. This specialized skillset has been further refined through a strategic partnership with the renowned stage lighting brand Ayrton (**Figure 2** – Ayrton MagicPanel FX), allowing Gaggione to deepen its knowledge in color rendering capabilities.

Figure 2: Ayrton MagicPanel FX.

This strategic partnership — now extended to many top-tier manufacturers — is a key competitive advantage. To address the unique demands of this market, Gaggione has designed high-performance collimators, such as the LLC59N and LLC59C, which deliver exceptional color mixing uniformity and bring energy savings for the customers. **Figure 3** shows the performance of Gaggione's narrow beam optic vs competition.

Gaggione's technical mastery shines in the development of high-intensity beams — a field in which the company provides exceptional added value. Thanks to its engineering expertise and precision plastic injection capabilities, Gaggione can produce thick, complex optical components that are typically very challenging to mold and more prone to defects.

By consistently pushing technical boundaries, Gaggione has developed differentiated solutions that clearly distinguish it from competitors.

Figure 1: Gaggione headquarters.

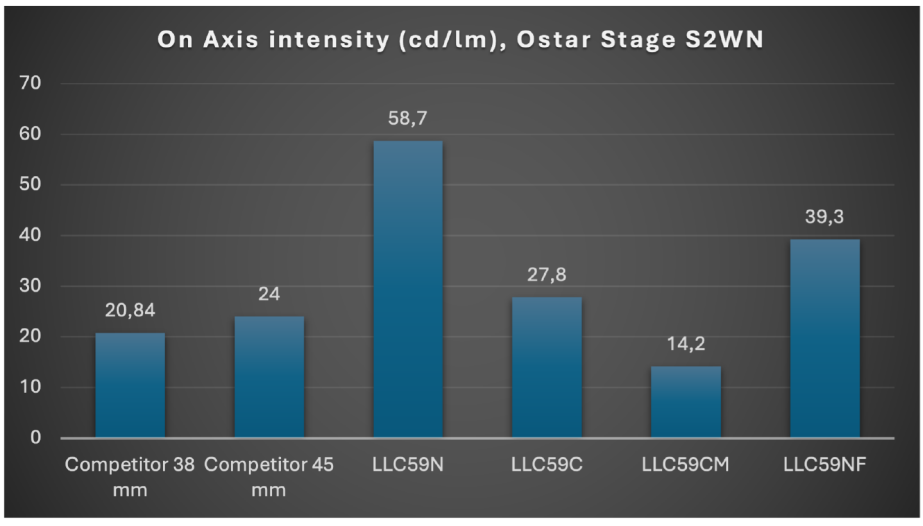


Figure 3: Performance of Gaggione's narrow beam optic vs competition.

An Expanded Standard Optics Offering

In 2024, Gaggione strengthened its market position by expanding its portfolio of standard optical solutions. Originally focused on collimators, the company broadened its product lines to address emerging applications.

The Pollux range was introduced, bringing linear optics tailored to indoor lighting needs — such as offices, retail spaces, and commercial buildings.

Simultaneously, the Avika range was developed to meet the demands of urban and outdoor lighting, with lenses optimized for those specific applications. More recently, the range has expanded to include

Amber-Orange (**Figure 4**) and Amber-Yellow (**Figure 5**) nightlife friendly road lighting optics.

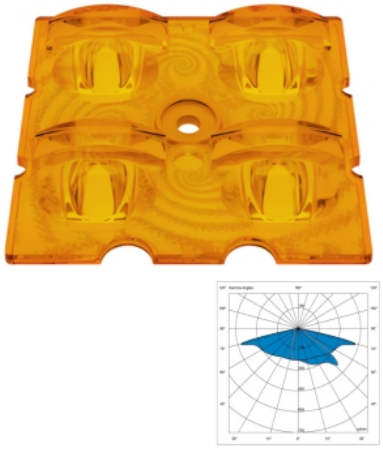


Figure 4: Amber-Orange optic.

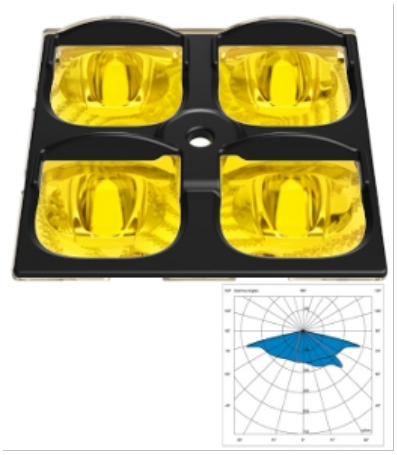


Figure 5: Amber-Yellow optic (LOR: 85%, CRI 68).

Gaggione's amber optic options are available with multiple photometries and backlight blocking masks. Gaggione can customize photometries, optical design and desired wavelength according to customer requirements.

Amber-Orange creates conventional sodium vapor like color temperature (1995K with 3000K LEDs, **Figure 6**) with as high CRI as 59 and LOR of 74%. Amount of blue light (380nm-500nm 0.007%).

The company also advanced its expertise in collimators with the launch of the Hadar70 range, specially designed for COB LEDs. A key innovation accompanies this launch: a clip-on "window"-type accessory that clips-on directly to the collimator, allowing beam adjustment without having to replace the optical part itself – a breakthrough in flexibility and cost-efficiency.

Continuing this momentum into 2025, Gaggione is further expanding its ranges. The Hadar range now includes 50 mm collimators (**Figure 7**), while Pollux offers

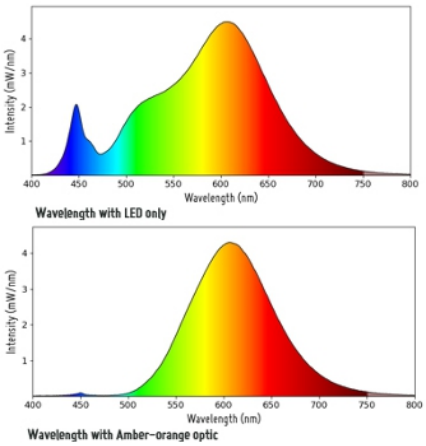


Figure 6: Wavelength comparison with Amber-Orange optic.

new beam angles and patterns. The Avika range is about to take a major leap forward with the development of specialized beam types tailored to demanding road lighting applications — such as tunnels and parking lots.

Figure 7: New Hadar50 range.

These next-generation solutions will enhance Gaggione's portfolio by delivering:

- High-performance illumination
- Exceptional durability
- Precision-optimization for complex environments

Through these strategic developments, Gaggione reaffirms its dual commitment to innovation and market responsiveness, ensuring ever-more powerful and diverse optical solutions to meet the evolving needs of the market.

Benchmark

In a market where standard optical components are becoming increasingly competitive, Gaggione has made the strategic choice to stand out not only through the quality of its optical performance but also by aligning its pricing with current market expectations.

This carefully balanced approach allows the company to maintain strong competitiveness without compromising on performance. Gaggione have also created Color Consistency Index[4] to accurately measure and quantify the color mixing performance of the optic.

- CCI = Color Consistency Index, lower value is better
- CCI 1-2 – Not visible to the naked eye
- CCI 2-5 – Hardly visible to the eye
- CCI 5 and more – Clearly visible to the eye

Figure 8 illustrates 10-degree (FWHM) color mixing optics, both 45mm diameter.

Summary

Gaggione, a French optics expert, showcased advanced technologies at GILE 2025, highlighting custom and standard optical solutions. With innovations in color mixing, recycled materials, and urban lighting, Gaggione expands its global reach. Its standard range now includes amber optics and COB collimators, balancing performance, cost-efficiency, and environmental responsibility. ■

[4] https://www.optic-gaggione.com/gaggiones-technology/color-consistency-index/

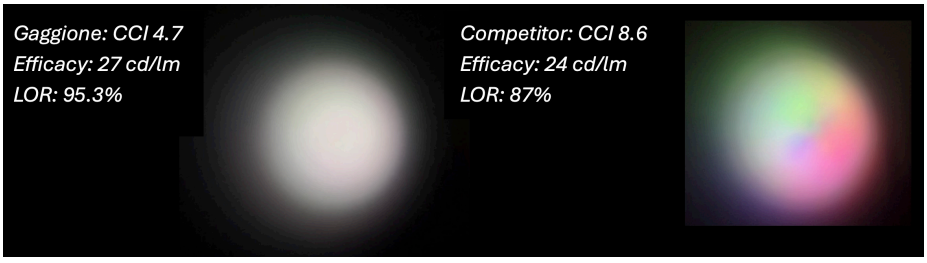


Figure 8: Comparison of color mixing optics.

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The Next Generation of Human-Centric Lighting: "Incandescent LEDs" and Their Hidden Health Power

Dr. Alexander Wunsch, MD, PhD

Introduction

In the artificial lighting industry, it has long been fashionable to work with high correlated color temperatures (CCT) in an effort to mimic sunlight. Yet reproducing sunlight in all its complexity - intensity, timing, spectrum, modulation, color rendering - is impossible with current technology, requiring choices on which parameters match.

During the fluorescent lamp era, neither high-quality color rendering nor high intensity could be achieved economically. This left CCT as the preferred marketing metric for "sun-like" qualities, largely because cool light sources could easily produce abundant short wavelengths. It was cheaper and more efficient to make fluorescent lamps with CCTs above 3,000 K - often up to 16,000 K. Sunlight's CT at noon is around 5,700 K (a real temperature!), which became the supposed benchmark for a "natural" photonic environment, as long as one accepts the equation CCT = CT.

When LEDs replaced fluorescent lamps in nearly all applications, their first incarnations - cold white, bluish light - were harsh to eyes accustomed to the warm glow of incandescent lamps. Compared to these early LEDs, even most fluorescent lamps seemed gentler. Western LED manufacturers clung to outdated dogmas: flicker wasn't worth avoiding, a CRI of 80 was "good enough", and CCT was synonymized with the real black body emission at real temperature (=CT). Not so in parts of Asia. While some companies followed the old rules, others innovated, eliminating flicker even in retrofit bulbs, achieving daylight-like color rendering, and even pursuing spectra that follow the blackbody radiation curve as closely as possible.

Some visionaries went even further, turning the LED into a "photon synthesizer". Contemporary LEDs can cover spectral ranges from 200 nm into the near-infrared (> 1,000 nm) and beyond. COB (chip-on-board) technology allows multiple LED species to be combined on a single substrate, filling spectral gaps. With specialized phosphors and pigments, the output spectrum can be tuned with remarkable precision - from midday sky to evening glow, or to match the incandescent lamp, which still represents the only electrical light source with a truly natural, continuous thermal spectrum.

Incandescent light - phased out as "energy-wasting" - remains unique: low in high-energy visible light (HEVL), rich in near infrared (NIR; > 700 nm), and still used in thermotherapy and baby care. Both sunlight and fire are thermal light sources whose spectra fall on the Planckian (blackbody) curve, to which life appears optimally adapted: e. g. CRI is 100 for fire, candlelight, unmodified incandescent lamps, and sunlight, regardless of the respective CT.

This article presents 12 + 1 compelling reasons for the health-promoting use of incandescent-like light generated by specialized COB LEDs, referred to here for simplicity as "incandescent LEDs."

#1 Spectrum Endorsed by Evolution

Humans are closely related to non-human primates, particularly Old World monkeys. Many physiological traits, including ocular spectral sensitivity, remain highly conserved. The photopic sensitivity curve (V(λ)) peaks at ~ 555 nm - virtually identical to the maximum transmission of leaf tissue, suggesting adaptation not to unfiltered sunlight but to the filtered light under a forest canopy.

Three archetypal light environments shaped primate evolution:

1. Open landscape – direct sunlight with high spectral power near 480 nm, strongly activating melanopsin pathways, driving sympathetic responses: elevated cortisol, melatonin suppression, and heightened alertness (**Figure 1 left**).
2. Forest canopy – green-dominated spectrum with reduced blue and red; NIR in relation to the visible radiation is several times higher than in open sun (**Figure 1 middle**), fostering parasympathetic, regenerative states.
3. Night – moonlit or dark - very low irradiance and NIR (= darkness), complete absence of melanopsin-relevant blue, supporting restorative processes and sleep.

For humans, the night environment changed in the past ~ 1 million years [1]: the use of fire transformed it into low-illuminance conditions with significant NIR exposure (**Figure 1 right**).

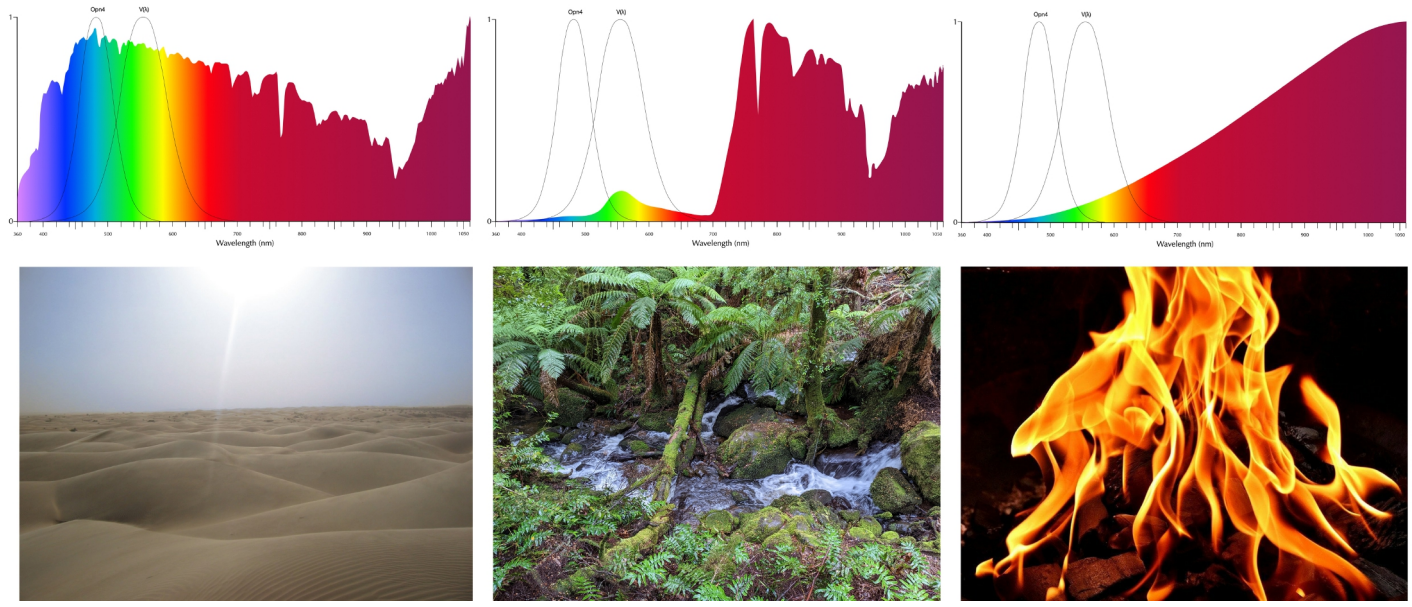

Figure 1: Archetypal light environments shaping primate evolution.**Left:** open landscape with direct sunlight, rich in blue wavelengths, activating sympathetic pathways. **Middle:** forest canopy spectrum, reduced blue and red but high near infrared, fostering regenerative states. **Right:** night/firelight with low illuminance, minimal blue and strong near infrared, supporting restorative processes.

Due to near-hairless skin, phototoxic vulnerability is increased: Humans had to develop distinct protective mechanisms for open-landscape exposure [2]. Transitioning from night or canopy to open terrain situation activates light-driven endocrine defense pathways: adrenaline-induced vasoconstriction limits erythemal skin blood flow, cortisol dampens inflammation, catecholamines stabilize cardiovascular function, and mineralocorticoids regulate fluid balance. These responses operate at both systemic and local levels, "from brain to skin" [3,45].

Given this background, modern artificial lighting should be re-evaluated. Options include replicating the "steppe/desert" profile - high blue, strong sympathetic activation; the "oasis under the canopy" profile - low blue, high daytime NIR, neutral vegetative tone; or the pre-electric "night" profile, characterized by the natural blackbody spectrum of fire, rich in NIR, free of HEVL and with minimal blue to allow uninterrupted melatonin secretion. Chronobiologically, the latter two modalities align more closely with today´s (motorically reduced) indoor tasks and offer long-term health benefits by avoiding maladaptive systemic stress reactions.

#2 Low HEVL Content

High-energy visible light (HEVL, ~ 400–460 nm, sometimes up to 470 nm) carries the highest photon energy in the visible spectrum (~ 3.1 eV at 400 nm) and is strongly linked to photo-oxidative stress in eye and skin.

Ocular effects – In the retina, HEVL is absorbed by lipofuscin and other chromophores in the retinal pigment epithelium (RPE). Blue-light-induced damage, not sufficiently described by the Blue Light Hazard (BLH) function, is cumulative and accelerates age-related macular degeneration (AMD). Children and aphakic/pseudophakic eyes filter less short-wavelength light, increasing hazard compared to the standard BLH curve.

Skin effects – HEVL penetrates deeper than UVB, reaching the upper dermis where it promotes reactive oxygen species (ROS) formation. This accelerates collagen breakdown, hyperpigmentation, and photoaging. Damage is primarily oxidative rather than direct DNA injury, making it cumulative and harder to detect.

Indoor overexposure – In sunlight, HEVL is balanced by red/NIR wavelengths that help modulate oxidative stress [6–10]. Standard white LEDs, especially with CCT > 4,000 K, often have intense HEVL nm peaks without compensatory NIR, exposing indoor workers to significant cumulative oxidative loads. Reducing 400–460 nm output lessens ocular and dermal oxidative stress [11], especially for:

- Children (clear lenses, large pupils)
- Post-cataract patients (implant lenses have higher short-wavelength transmission)
- Elderly with AMD risk
- Photosensitive skin conditions

Incandescent LEDs produce a smooth spectrum with minimal HEVL and no sharp 450 nm spike (**Figure 2**), closely resembling the natural firelight spectrum shaped by evolution. This lowers cumulative photo-oxidative risk while maintaining full visual performance.

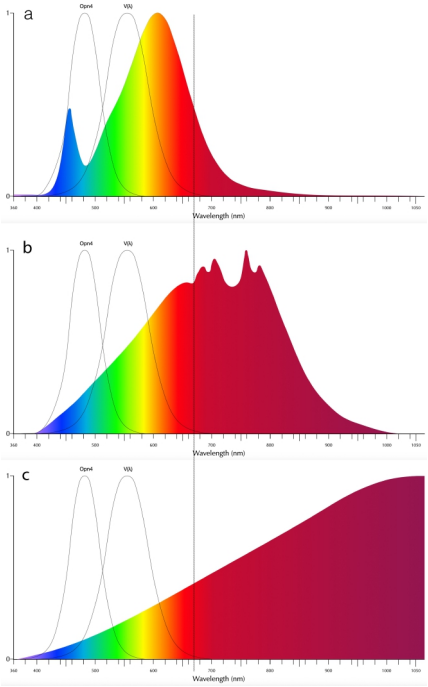

Figure 2: Spectral comparison of standard LED **(a)**, NIR-enriched incandescent LED **(b)** and classic incandescent lamp **(c)**. The spectral curves of the incandescent lamp and LED in the visible part are almost identical regarding continuity and blackbody.

In contrast to HEVL, blue light, particularly near 480 nm, is vital for circadian entrainment, therefore short wavelengths should not generally be eliminated indoors but applied reasonably balanced and timed:

sufficient to sustain non-visual functions without chronically overstimulating the melanopic pathway or causing excessive oxidative stress. For long-term circadian adaptation support, higher CCT (> 4,000 K) exposure with spectral emphasis around 480 nm and reduced HEVL can be applied intermittently, tailored to the individual, and paired with plenty of protective NIR.

#3 Restoring Near Infrared

In sunlight and fire, near infrared (NIR; > 700 nm) makes up at least 40% of total radiant energy [9]. Though invisible, it penetrates deeply into tissue [12], interacting with water, hemoglobin, and mitochondria, and plays a key role in cellular physiology.

Physiological relevance – NIR is absorbed by mitochondrial chromophores, especially cytochrome c oxidase, boosting ATP production, improving microcirculation, and enhancing antioxidant defenses [6]. This photobiomodulation (PBM) supports tissue repair [13], modulates inflammation, and in the retina can counter oxidative stress from high-energy visible light (HEVL) [14]. Low intensity exposure (8 mW/cm^2) to deep red/NIR (~ 670 nm) has been shown to improve retinal sensitivity and mitochondrial efficiency in aging eyes [15].

Modern artificial light, especially phosphor-converted LEDs, cuts off above ~ 630–700 nm due to v(λ)-driven efficiency design, creating a chronic NIR deficit for those mostly sitting indoors behind "climate-friendly" windows filtering NIR for energy efficiency's sake.

Incandescent LEDs can provide significant NIR, with output extending up to ~ 1,000 nm - enough for PBM effects but without the intense heat of wavelengths > 1,500 nm (**Figure 2**). The NIR level can be tailored for the intended application at the expense of nominal energy efficiency.

Biological implications – NIR can mitigate HEVL damage by "preconditioning" tissue (e.g., 630–850 nm), improving resilience in skin and eye. Including NIR in daily lighting reintroduces a natural spectral element largely absent in modern interiors.

#4 Improved Photobiological Safety

Conventional white LEDs emit a pronounced high-energy visible light (HEVL) peak (~ 400–460 nm), generating reactive oxygen species (ROS) in the eye and skin. In ocular tissues, this contributes to cumulative oxidative stress in the retinal pigment epithelium (RPE), photoreceptors, and lens. The negative impact of conventional LEDs on ocular health has been underestimated from the beginning, and growing evidence [16–18] has been systematically ignored by regulatory bodies and standards [19,20].

Incandescent LEDs have minimal HEVL and are rich in near infrared, producing a more balanced spectrum. NIR is non-phototoxic at normal levels and activates mitochondrial cytochrome c oxidase, enhancing metabolism, antioxidant defenses, and tissue repair. By combining low HEVL with ample NIR, incandescent LEDs reduce phototoxic stress while enabling intrinsic repair, aligning artificial lighting with evolutionary photobiological safety.

#5 Hormone Neutrality

Light is both a visual and endocrine signal. Short-wavelength content strongly influences hormonal balance via intrinsically photosensitive retinal ganglion cells (ipRGCs), which peak near 480 nm. These cells project to the suprachiasmatic nucleus (SCN), regulating pineal melatonin and triggering broader neuroendocrine responses [3,21,22].

Melanopic stimulation suppresses melatonin but also engages the hypothalamic–pituitary–adrenal (HPA) axis, raising cortisol, adrenaline, and noradrenaline. Excess blue-rich light at inappropriate times can cause chronic sympathetic activation, contributing to cardiovascular strain, metabolic disruption, and immune suppression [4,23,24].

In the 1970s, Fritz Hollwich showed that altered artificial spectra produced by fluorescent lamps elevated catecholamine breakdown products, indicating heightened sympathetic tone - later confirmed by mapping the ipRGC–SCN pathway [25–27]. Until the full description of the neuronal pathways in 2001 [28], the lighting industry denied these vegetative effects, and after 2001 the effects were reframed as "melatonin suppression," downplaying pituitary axis and stress hormone involvement.

Hormone-neutral lighting meets visual needs while keeping melanopic and non-visual stimulation within physiological limits - especially outside peak daylight hours. Incandescent-type spectra, including modern incandescent LEDs, have low melanopic/photopic ratios and minimal HEVL, reducing melatonin suppression and HPA activation, thus supporting endocrine individuality.

This is especially important for:

- Children/adolescents with developing endocrine systems
- Cardiovascular patients, where extra sympathetic drive is risky
- Those with sleep, mood, depression or anxiety disorders [29,30]

#6 Individual Hormonal Compatibility

Light's endocrine effects vary greatly with age, sex, genetics, chronotype, ocular status, health, and medication use. This makes "one size fits all" lighting inherently suboptimal - and sometimes harmful - for certain groups.

Variability factors:

- Chronotype: Evening types are more sensitive to evening short-wavelength light, which delays circadian phase.
- Age: Children's clearer lenses transmit more blue/HEVL, increasing melanopic stimulation and lifetime increase in SW dose [11].
- Lens status: Post-cataract patients with clear or blue-transmitting IOLs (intraocular lens implants) receive more short-wavelength retinal irradiance; risk for AMD increases [31,32].
- Sex hormones are affected by light, depending on brightness and timing [33,34].
- Medications: Pharmaceuticals such as beta blockers, corticosteroids, antidepressants, and others can alter physiological light responses by impacting the stress hormone axis or affecting melatonin production.

Risks of blue-enriched light – Morning exposure may boost mood in healthy adults but could raise sympathetic tone, blood pressure, or delay sleep in those with cardiovascular, anxiety, or immune disorders. Effects depend on both the melanopic/photopic ratio and the individual's baseline hormonal state.

Clinical implications – A light spectrum that stimulates hormones in one person may harm another. Most general lighting lacks such tailoring, meaning some occupants will be exposed to spectra that disrupt rather than support their hormonal balance.

Incandescent LEDs, with low impact on cellular and endocrine-vegetative integrity, are suited for kindergartens, schools, hos-

pitals, elder care, dementia care and diverse workplaces.

#7 Compatible with All Ages

Photobiological safety standards are based on healthy (male?) adults, overlooking spectral and anatomical differences in children, elderly individuals, and post-cataract patients [35].

Children – Their crystalline lens is highly transparent to short wavelengths, including violet and near-UV light. Aphakic people (without a natural lens or clear IOL) suffer from this transparency in adulthood. For these groups, the aphakic blue light hazard (BLH) function - showing higher HEVL/near-UV retinal exposure - is more accurate than the standard BLH curve.

Age-related transmission – Differences decline above ~ 500 nm, where elderly, young, and aphakic eyes transmit light similarly [47]. The common recommendation to increase light for the elderly "fourfold" is mostly relevant for short wavelengths; above 500 nm, only about a twofold increase would be needed.

Implications:

1. Energy efficiency: Warm, low-HEVL spectra can meet elderly brightness needs with less than half the extra energy compared to the "4× rule."
2. Spectral safety: Reduced-HEVL light especially protects children and post-cataract patients from retinal phototoxicity.

A warm, low-HEVL spectrum is thus safest and most efficient across all ages, delivering good vision while minimizing avoidable risk.

#8 Sharper Vision

Visual acuity is limited by optical quality and chromatic aberration - the wavelength-dependent focus error caused by refractive index changes in ocular media. Longitudinal chromatic aberration (LCA) is ~ 2 diopters between 400 nm and 700 nm, with short wavelengths (violet/blue) focusing in front of the retina (**Figure 3 a**).

Approximate LCA vs. 555 nm

- 400–450 nm: +1.0 to +1.5 D → strong defocus, fringes, glare, contrast loss
- 450–500 nm: +0.5 to +1.0 D → moderate defocus, blur
- 500–600 nm: minimal LCA → sharpest focus
- 600–700 nm: –0.3 to –0.5 D → slight defocus

Short-wavelength defocus scatters light on the retina, lowering contrast - most noticeable under high blue content (cold LEDs, snow, water reflections). In precision tasks (aviation, sailing, skiing, marksmanship), yellow/amber filters cutting < 500 nm improve contrast and edge definition (**Figure 3 b**). Warm, low-HEVL sources like incandescent LEDs reduce chromatic blur naturally, enhancing visual comfort and acuity without filters.

#9 Excellent Color Rendering

Color rendering depends on how faithfully a light source reveals colors compared to a natural reference. Humans evolved under continuous thermal spectra (sunlight, fire), all lying on the Planckian locus and scoring a perfect CRI of almost 100. These spectra stimulate all three cone types (S, M, L) in balanced proportions, ensuring natural color perception and minimal metameric mismatch.

Limits of modern metrics – CRI (Ra) can misrepresent narrow-band or "spiky" spectra like fluorescent and standard LEDs. Alternatives (IES TM-30's Rf/Rg, CIE methods) capture more nuance but still favor smooth spectra.

Spectral engineering pitfalls – Non-thermal light sources can be tuned to achieve high CRI scores on standardized test samples yet still perform poorly with real-world colors, particularly saturated reds (R9) and deep blues - crucial in medicine, food presentation, and art. The pursuit of maximum color fidelity often conflicts with spectral optimization for biological safety; reducing HEVL or boosting red and NIR content can lower nominal CRI, though values above 90 and even 95 remain achievable.

Following the blackbody curve, incandescent LEDs reproduce full-spectrum reds and deep reds (> 600 nm) without simulated peaks. This delivers accurate skin tones, consistent object colors, and reduces cognitive load from spectral correction, improving visual comfort during prolonged tasks.

#10 Flicker-Free Operation

Incandescent lamps on mains AC exhibit a small 100/120 Hz modulation (~ 3–5%) from filament heating and cooling. LEDs, however, can produce anything from harsh, almost stroboscopic flicker across multiple frequencies to virtually zero flicker, depending on driver design - an engineering choice. Light flicker, whether visible or sub-perceptual, can trigger headaches, eyestrain, reduced visual performance,

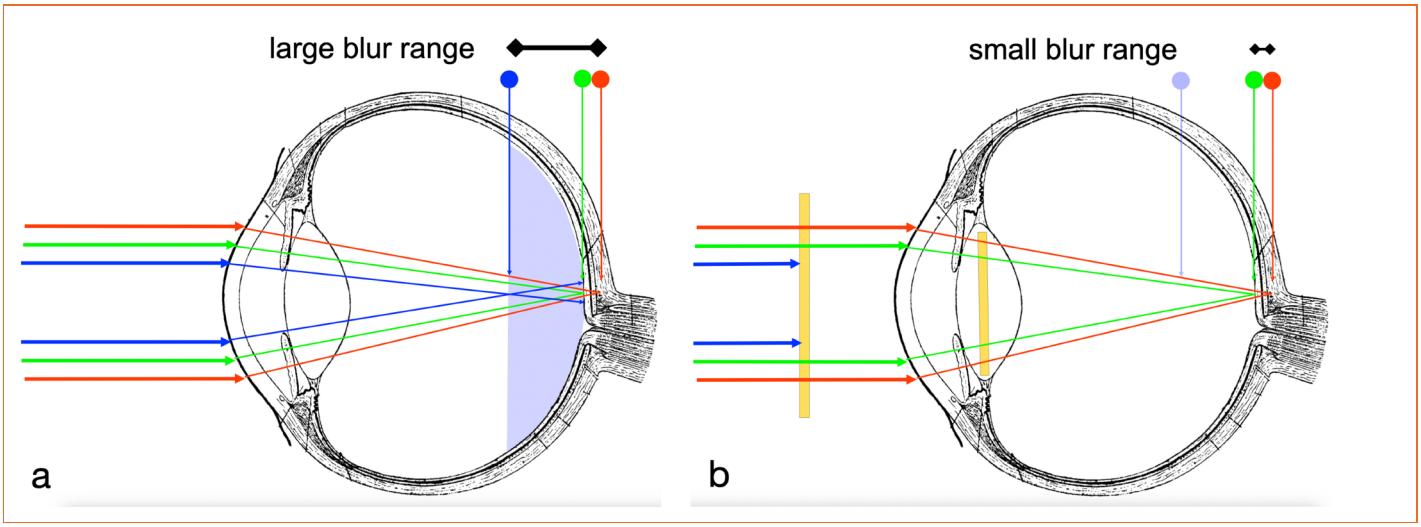

Figure 3: Longitudinal chromatic aberration and resulting defocus for blue-rich **(a)** and blue-filtered **(b)** conditions.

and exacerbate migraine, photosensitive epilepsy, or mood disorders [36–39]. Even beyond conscious detection thresholds, it can elicit cortical responses and disrupt eye movement stability [38,40].

Since LEDs operate on low-voltage DC, electronic circuitry is unavoidable, but it can be designed for modulation-free operation. This is both technically feasible and inexpensive, effectively eliminating this biological stressor.

#11 Psycho-Emotional Benefits

Light shapes emotional state, social perception, and self-image. Warm-spectrum light, like that from incandescent LEDs, feels inviting, flatters skin tones, and fosters relaxation and positive interaction.

Blue-enriched light (~ 470–490 nm) increases amygdala activation, heightening vigilance and, with chronic exposure - especially at night - potentially increasing anxiety [41,42]. Aesthetically, it reduces warm skin reflection, accentuates superficial blood vessels, and can give a pallid or cold appearance. Warm spectra enhance subdermal scattering, mask vessels, and produce a healthier look.
Such psycho-emotional and aesthetic effects influence mood, communication, and productivity. Choosing spectra that support both physiology and psychology is as important as meeting visual task needs.

An important publication demonstrated that malillumination is associated with increased prevalence of certain psychological disorders [30]. To translate these findings into everyday lighting practice, it is essential to have hormonally neutral light sources like the incandescent LED available - particularly those with low color temperatures - to minimize melanopic stimulation and its potential impact on neuroendocrine balance.

#12 True Cost Efficiency

Energy efficiency metrics rarely include the health costs of chronic exposure to biologically unbalanced light, which may raise risks for cardiovascular disease (CVD), age-related macular degeneration (AMD), cancers , metabolic disorders, and mood conditions [43–46]. These costs can vastly exceed the small electricity savings from the most efficient - but physiologically suboptimal - light sources.

Example 1 – AMD Treatment vs. Lamp Energy

Treating one wet AMD patient in Germany costs ~ €30,000/year. A 100 W incandescent lamp run 24/7 uses 876 kWh/year, costing ~ €263 at €0.30/kWh. For the price of one year of AMD treatment, ~ 114 such lamps could run 24/7 for a year - or one personal lamp for one and a half human lifetimes.

Example 2 – Cardiovascular Diseases Costs vs. National Lighting Savings

CVD costs Germany ~ €80 billion/year. Comparing the incandescent LED to a slightly more efficient but biologically inferior LED might save €5/year per luminaire. Across 100 million luminaires, that's €0.5 billion/year - less than 0.7% of CVD costs. Even a small rise in CVD burden would erase any savings many times over.
Conclusion – Marginal gains in luminous efficacy cannot justify spectra that harm health. Incandescent LEDs - with low HEVL, high NIR, excellent CRI, and evolutionary compatibility - are more cost-effective long term when health care costs are included.

#12+ One Last Thing – Regulatory Perspective

Under both European and international frameworks, a medical device is defined as any instrument, apparatus, or other article intended by the manufacturer to be used for human beings for a medical purpose, such as diagnosis, prevention, monitoring, treatment, or alleviation of disease. In the EU, the Medical Device Regulation (MDR 2017/745) explicitly includes products that exert their principal intended action by physical means - such as light - if that light is meant to achieve a physiological effect for health purposes.
This definition creates a regulatory grey zone for modern "biologically active" lighting technologies. If a light source is marketed or designed to deliberately influence physiological parameters - such as melatonin secretion, alertness, and circadian phase shift - it may, in principle, fall under medical device regulation. This would trigger requirements for:

- Clinical evidence of safety and efficacy.
- Quality management systems for production.
- CE marking under the MDR, with possible classification above Class I.
- Ongoing post market surveillance.

The Human Centric Lighting Paradox

So called "human centric" or dynamic lighting systems are explicitly intended to influence nonvisual physiological functions - often marketed with claims about boosting mood, performance, or circadian alignment. In a strict legal interpretation, such intended use could place them in the medical device category, especially if any therapeutic or preventive health claims are made. However, enforcement is inconsistent, and most such products currently enter the market without MDR conformity assessment.

Why the Incandescent LED Is Different

The incandescent LED provides a spectrum closely resembling traditional incandescent lamps. Its primary function is general illumination, and it can be specified and sold without any intended medical purpose. As such, it does not trigger medical device classification. Physiological compatibility is achieved as a byproduct of its neutral spectral qualities, not through targeted photobiological intervention.

From a regulatory risk perspective, this is significant:

- No additional conformity burden: It remains a standard lighting product under low voltage and EMC directives (and possibly eco design rules), not MDR.
- Lowest physiological interference: Because it avoids extreme spectral manipulations, its negative impact on hormonal, retinal, and vascular parameters is minimal.
- Avoids claim based reclassification: By not marketing it as a therapeutic or preventive tool, the manufacturer avoids crossing into regulated medical territory.

The Strategic Advantage

For specifiers and facility managers - especially in hospitals, care homes, schools, and workplaces - the incandescent LED offers a safe regulatory position combined with a biologically favorable spectrum. It sidesteps the compliance uncertainties that could emerge for biologically active lighting in future legal reviews, while still delivering the health aligned qualities many facilities want.

Conclusion

COB technology enables the incandescent LED - more efficient than tungsten yet providing all key advantages: high CRI, natural blackbody spectrum, NIR enrichment, and low HEVL. As a hormonally neutral, health-supportive light source enabling optimal vision for all ages, it merits a central role in future healthcare, lighting design, and computer display technology. ■

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Dr. Alexander Wunsch, MD, PhD

Dr. Alexander Wunsch, MD, PhD, is a physician, light therapist, independent researcher, and scientific consultant. From 2008 to 2019, he served as a lecturer in the Master of Arts program in Architectural Lighting Design at Wismar University of Applied Sciences. His research is focused on the physiological and pathological effects of light on humans, and he has been a vocal critic of the ban on incandescent lamps. His work advocates for a paradigm shift in the field of photobiology and calls for a health-centered redefinition of lighting standards. Dr. Wunsch emphasizes the necessity of shifting from the utilization of energy efficiency as the predominant criterion for indoor lighting, promoting instead the adoption of salutogenic lighting concepts grounded in human biology. This approach prioritizes the beneficial impact on health over considerations of technical or economic feasibility.

wunschart@gmail.com

Sustainable Public Lighting, Part II: Challenges and Potentials of Future Technologies

Dipl.-Ing. Johannes Weninger[1,2], MMag. Martina Ascher[1], Maximilian Dick[1], MSc.; Bartenbach

Many of the existing requirements regarding public lighting can be addressed by forward-looking technologies (e.g., IoT or intelligent, self-adaptive control systems). However, the sustainable integration of such technologies into the market and the further utilization of their potentials strongly depend on overarching limiting factors along the entire value chain. Ensuring the success of environmental and climate policy efforts therefore requires consideration of the diverse requirements of various stakeholder groups.

On behalf of the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), Bartenbach developed comprehensive recommendations for action based on a stakeholder survey, with the aim of supporting the long-term achievement of national and international sustainability goals. Following the discussion of thematic challenges in the first part of this two-part article series, the present second part focuses on technological potentials and limitations, as well as the resulting recommendations for action.

Introduction

Technological innovation has always played a central role in shaping public lighting systems. However, today's global challenges, such as climate change, increasing urbanization, and growing resource scarcity, are leading to a fundamental rethinking of existing systems. The resulting shift moves public lighting away from static infrastructure and toward intelligent, adaptive networks [1]. In theory, this transformation unlocks substantial ecological, economic, and social potential. Benefits range from reduced energy consumption [2] and light pollution [3] to enhanced safety and an overall improvement in urban quality of life.

At the heart of this development are LED systems. Compared to traditional lighting technologies, they offer not only superior energy efficiency and longevity, but also new opportunities enabled by digitalization. Sensor-integrated lighting, AI-based control systems, and real-time data processing allow lighting to dynamically respond to environmental conditions, traffic flows, and human presence [4]. Digital twins, predictive maintenance tools, and connected systems provide further advantages in planning, monitoring, and optimization [5].

Research plays a crucial role in realizing these potentials by providing evidence-based insights into user needs [6], environmental impacts [7], and technical performance [8]. It also serves as a key driver of innovation in interface design and system integration [9], forming the foundation for scalable and sustainable solutions. In addition, interdisciplinary studies help align lighting technologies with broader urban and ecological objectives, such as biodiversity preservation [10] or perceived nighttime safety [11], based on an expanded knowledge base.

Despite significant progress in many areas of development, market adoption remains uneven. Potential barriers include regulatory inertia, limited awareness among decision-makers, and uncertainty about long-term costs and returns on investment. Many municipalities face tight budgets or lack the necessary expertise required to evaluate lighting solutions considering the complex field of requirements. The rapid pace of digital innovation often leaves standardization mechanisms lagging behind, and current planning tools frequently fail to reflect the real-world variability of urban environments.

To fully leverage the potential of public lighting technologies, these barriers must be addressed through coordinated efforts in policy, research, and product development. Establishing the right framework conditions is a necessary first step toward making future-oriented lighting technologies a key contributor to sustainable urban transformation.

Commissioned by the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), Bartenbach conducted a comprehensive assessment of current and emerging lighting technologies, evaluating their ecological, economic, and social potential. This included aligning technological capabilities with complex thematic requirement profiles and identifying key implementation barriers through a stakeholder survey spanning the entire value chain. The outcome is a targeted action guide for Austrian public authorities, designed to ensure that technological advancements in public lighting can effectively support environmental goals by 2035. The insights from the stakeholder survey are presented in a two-part article series. While the first part explored responsibilities, environmental awareness, and the thematic challenges surrounding public lighting, this second part focuses on

[1] Bartenbach GmbH, 6112 Wattens, Austria
[2] Johannes.Weninger@bartenbach.com

www.bartenbach.com

technological solutions and the derived strategic recommendations.

Identification of Key Technologies

The key technologies examined in the survey were identified through a comprehensive comparison of current scientific knowledge and market developments. The scientific foundations, which reflect the thematic challenges of outdoor lighting, were discussed in detail in the first part of this article series. Existing technological approaches were assessed by a systematic review of product portfolios from a broad range of outdoor lighting manufacturers.

The analysis included both technical and architectural-decorative lighting sectors. Smaller companies were deliberately included to ensure that innovative but less widely commercialized solutions were also captured. The product review was not limited to specific applications and encompassed street lighting, building and object illumination, as well as lighting for paths, plazas, parking lots, and pedestrian zones.

All relevant products were subjected to a qualitative, multidimensional classification (**Table 1**), assessing aspects such as optical technologies, light quality, interoperability, ease of maintenance, connectivity, production methods, and environmental impact. Functionalities were documented and evaluated based on their availability within each portfolio.

Evaluation criteria were defined in advance and encompassed both established parameters (e.g., color temperature ranges, glare control) and forward-looking features, such as dynamic light distributions. Additional focus was placed on innovative materials (e.g., biogenic components), energy-saving concepts, and compatibility with next-generation control technologies like 5G and 6G. The compiled data was then analyzed for feature prevalence across manufacturers.

By aligning these insights with the scientific literature, six key technologies were identified, each addressing multiple thematic challenges and offering scalable, future-oriented potentials.

Technological Challenges and Potentials

To assess both the potential and possible limitations of the identified key technologies, survey participants (a characterization of the survey participants can be found in the first part of this article series) evaluated the impact of each technology on various factors: environmental aspects (light pollution, energy consumption), user-related issues (health, privacy, acceptance), safety (subjective and objective), complexity (planning, standardization, interface definition), as well as production costs, maintenance needs, and technological sovereignty. Responses were recorded on a 7-point Likert scale (1 = very negative impact, 4 = no impact, 7 = very positive impact).

To ensure comparability given respondents' diverse backgrounds and levels of expertise, all questions included anchored prompts outlining both potential benefits and challenges.

Adaptive Spectral Compositions

For many years, the primary purpose of public outdoor lighting was to meet visual requirements centered exclusively on human needs. As environmental priorities have gained traction, reducing the harmful ecological effects of artificial lighting has become increasingly important. Ideally, night-time lighting should be minimized to reduce environmental impact. However, current lighting standards are still based on brightness as perceived by humans, although many animal species have visual systems that respond differently to various wavelengths of light. As such, the problem lies not only in brightness but also in the spectral composition of the light.

Biologists have long recognized that different wavelengths of light affect species in distinct ways. Birds, for example, have tetrachromatic vision, which includes sensitivities not only in the short-wavelength range but also in the long-wavelength parts of the spectrum [12]. Contrarily, hatchling sea turtles are predominantly drawn to blue-rich light, which prompted the introduction of turtle-friendly lighting regulations along Florida's coastlines [13].

Historically, efforts to reduce ecological disruption were limited by the capabilities of available lighting technologies. High-pressure sodium lamps, which emit longer wavelengths, were less attractive to insects, while mercury vapor lamps, with their ultraviolet components, were particularly alluring [14]. Today, LED technology allows for flexible spectral tuning, enabling more targeted approaches to minimizing light pollution [15].

The overarching goal is to align the spectral power distribution of lighting with the spectral sensitivities of specific species, thereby mitigating ecological impact. A growing body of research provides detailed insights into the light sensitivities of various animals [16], and studies have already shown that the ecological effects of artificial light at night are scientifically replicable [17]. However, the wide variability in visual systems among species poses a significant challenge. There is no universal spectrum that can ensure optimal visibility for humans at night while avoiding adverse effects on wildlife. Spectra designed to protect certain species may appear unusual or inadequate from a human perspective, requiring public outreach and education to build acceptance for nonstandard lighting aesthetics.

To overcome this challenge, adaptive lighting systems, which adjust spectral composition based on the presence of humans or animals, offer a promising path forward. These kinds of adaptive spectral systems are already used in applications like Tunable White lighting. However, while the underlying technology is similar to Tunable White and the science of spectral tuning is well established, market-ready products are still rare. Only a few pilot projects have been implemented, usually in urban settings, and typically accompanied by public

Category	Subcategory
Luminaire Type	Function of the luminaire; Special features
Optical Technology	Optical efficiency; System modularity; Glare control; LED type; System concept; Available accessories; Power by cluster/array
Light Quality	Dynamic light distribution; Array effects; Color effects; Color rendering; Optimized spectrum
Interoperability	Standardization; Compatibility
Ease of Maintenance	Tool-free maintenance; Retrofit capability
Connectivity	Sensor integration; Multifunctionality; Cabling effort; Remote maintenance
Production Method	Resources; Materials; Sustainability; Circular economy
Environmental Impact	Light pollution; Energy-saving methods

Table 1: Categories and subcategories used for the qualitative evaluation of product portfolios during the market analysis.

awareness campaigns to encourage acceptance of lower light levels and altered urban atmospheres.

One key barrier is the lack of planning guidelines and comprehensive data on species distribution. As a result, these lighting strategies are generally applied only in areas where protecting a particular species is a clearly defined priority. The main limitations, therefore, lie not in the technology itself, but in its practical implementation.

Survey responses reflect these dynamics (**Figure 1**). More than half of respondents view the environmental and energy-saving potential of such systems positively. Health and safety benefits are also recognized, since spectral optimization can take human sensitivities into account without compromising privacy. However, acceptance is rated as significantly reduced. The reasons are clear: the complexity of implementation, the lack of normative standards, and limited integration with existing control interfaces.

Moreover, the scientific findings on species-specific light sensitivity are not yet generalizable, complicating broader application in regulatory and planning contexts. Technical expertise required for correct implementation is also often lacking. Higher manufacturing costs are anticipated due to the need for more LEDs and sophisticated optics for color mixing. On the other hand, maintenance is seen as manageable, since centralized control is not always essential. Ultimately, respondents expect such systems to contribute to greater technological sovereignty, especially given the growing market potential that should be secured over the long term.

Adaptive Light Distributions

A significant portion of public lighting is dedicated to streets, and due to increased lighting requirements for traffic safety, this segment contributes heavily to light pollution and municipal energy consumption. Optimizing street lighting is therefore a key strategy for adapting cities to ecological transformation.

Today, LEDs already play an important role in reducing energy consumption, especially when road surface reflectance is considered during planning [18]. However, the optical characteristics of road surfaces vary depending on weather and moisture. Whether the road is dry, damp, wet, or soaked significantly affects its reflectivity. This impacts average luminance and luminance uniformity, both essential regulatory criteria. To account for this, standards already allow for reduced uniformity requirements in wet conditions. However, reduced uniformity does not address increased glare from reflections on wet roads, which impairs visibility and driver performance. To effectively address this problem, both the luminous flux and its spatial distribution would need to be adjusted when brightness or glare conditions change.

While the issue is acknowledged in practice, current outdoor lighting systems cannot adequately provide variable light distributions. Unlike indoor systems that use mechanically adjustable components,

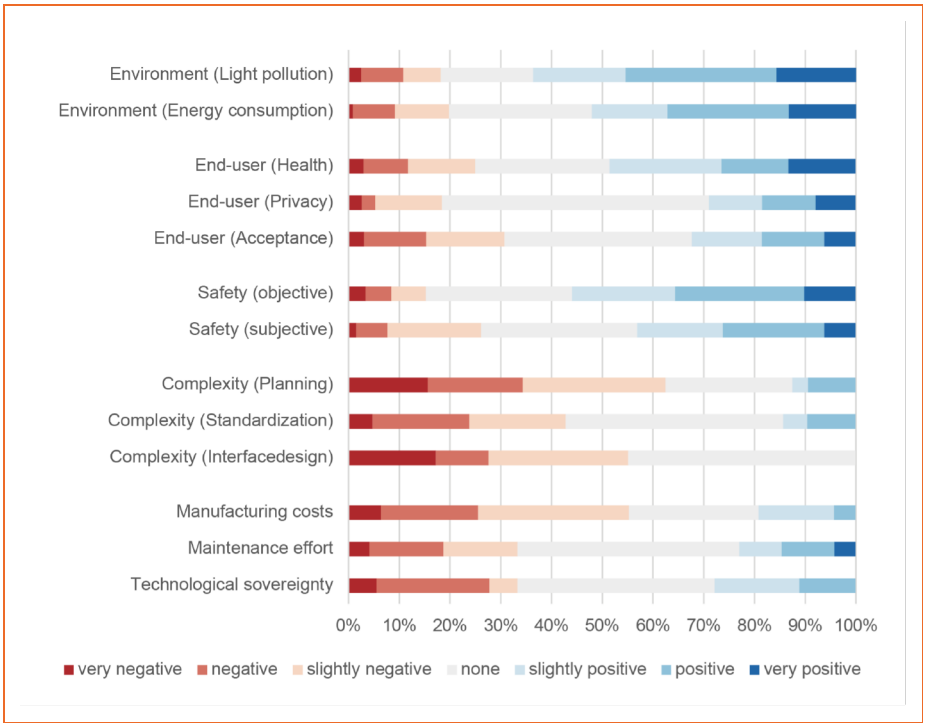

Figure 1: Multidimensional impact assessment of the technology area "adaptive spectral compositions"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

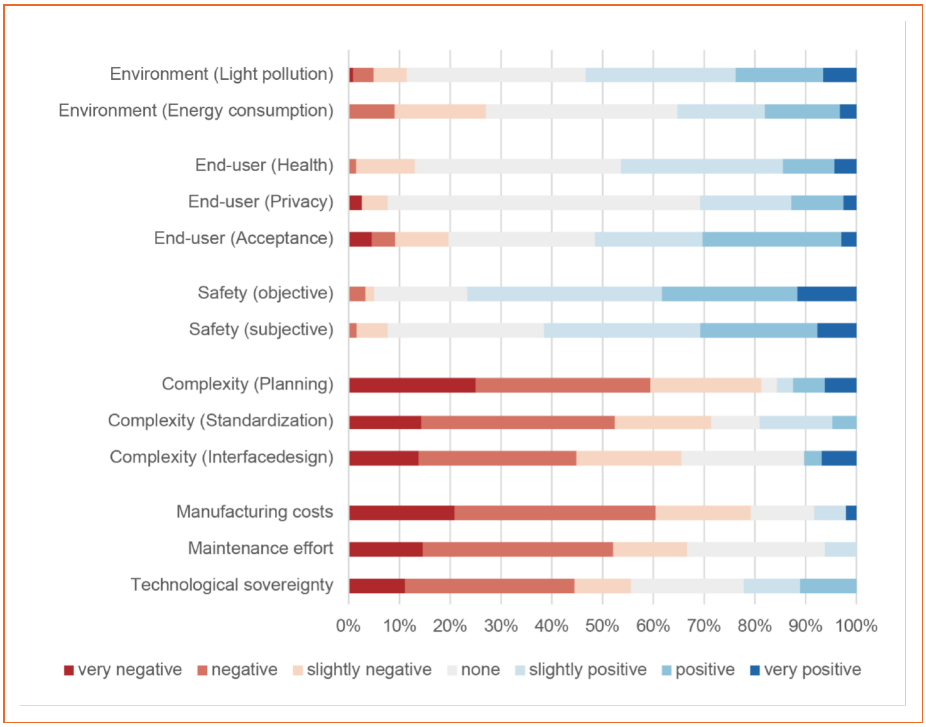

Figure 2: Multidimensional impact assessment of the technology area "adaptive light distributions"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

such solutions would be too maintenance-intensive for outdoor use. The only workaround so far has been dual systems with different beam profiles, which prove inefficient and resource heavy.

Yet addressing this issue could yield significant benefits, such as improved traffic safety through reduced glare and greater potential for energy savings. Simulation studies [19] show that systems designed according to normative standards often lead to excessive lighting when road surfaces are wet. In contrast, weather-adaptive lighting systems could significantly improve uniformity and reduce energy usage by up to 22% through adjusted luminous output.

To unlock this potential, new systems capable of adjusting light distribution must be developed. However, implementing variable light distribution remains a major challenge for the lighting industry. Potential approaches without moving parts remain largely in the research phase.

Against this technological backdrop, survey respondents' views appear well justified (**Figure 2**). Around 50% rated the impact of adaptive systems positively, particularly regarding environmental impact reduction, improved energy efficiency, and user-related health and acceptance. No significant concerns were raised about privacy, which aligns with the technology's neutral stance on that issue.

However, respondents rated the complexity and limitations of implementation as high. Negative evaluations were reported in areas such as planning feasibility, regulatory alignment, and system control interfaces. These difficulties stem from both technological and planning-related constraints. For instance, it remains uncertain how regulatory frameworks could adapt to variable light distributions or whether technical implementation in practice is even feasible.

From a planning perspective, over 80% of respondents expressed concern. This is likely due to the growing number of variable parameters in lighting design and the lack of reliable data on surface properties, which prove to be critical for accurate modeling. Current standards, which rely on tabular classifications, fail to capture the real-world variability required for effective planning.

Additional concerns include anticipated increases in production costs due to system complexity and optics, along with higher maintenance demands driven by control requirements. Finally, a loss of technological sovereignty is expected, particularly if market demand fails to justify the level of investment needed for such advanced systems.

Nanotechnology-based Optical Components

In modern lighting applications, diffusely emitting components are often used due to their low development and manufacturing costs. However, these systems present significant drawbacks in terms of lighting performance. Unguided light distribution leads to reduced efficiency, high levels of scattered light increase glare, and the lack of directional lighting impairs both depth perception and the recognition of object details. As a result, diffuse systems are unsuitable for functional outdoor lighting and are increasingly avoided in decorative applications due to their environmental impact [20].

Direct-emitting systems, by contrast, are essential for reducing light pollution in outdoor spaces. Freeform optical surfaces can now be precisely calculated, but practical challenges remain. Variations in LED color or production tolerances, such as positioning inaccuracies, can lead to visual artifacts like color-over-angle effects, edge highlights, or uneven light fields, all of which require compensation that diffuse systems don't.

To address these issues, micro-faceting of freeform surfaces is commonly used to increase system robustness. However, as LED components have become smaller [21], facet dimensions must be reduced accordingly to maintain beam quality. This introduces new manufacturing hurdles and places limits on further improvements in energy efficiency and visual comfort. Nanotechnology-based fabrication methods offer promising solutions, allowing for much finer facet structures, but they also introduce new demands across the production process.

In general, design and simulation tools for optical surfaces must account for manufacturing constraints to produce feasible geometries. However, little is currently known about the limits of nanofabrication, especially regarding the curvature, continuity, and smoothness of surfaces at such small scales. Moreover, the miniaturization of facets increases the data volume required for accurate modeling, which necessitates new data formats and highly parallelized simulation methods, such as Monte Carlo ray tracing.

On the production side, significant limitations persist. High-precision fabrication techniques, like two-photon polymerization combined with UV polishing, show promise. They can be used to create master templates that are then replicated using nickel electroforming. However, manufacturing components at the required scale and curvature remains a challenge. For instance, UV polishing is only viable for relatively simple surfaces, as it requires uniform energy delivery across all surface points [22]. This makes it difficult to combine micro-faceting with complex curvature, an essential requirement for advanced optics.

Even though conventional manufacturing processes in Europe already produce high-quality optical components, further scaling down is increasingly difficult. To reduce environmental impact and improve the energy efficiency of lighting systems, the industry must look to nanotechnology to push the boundaries of miniaturization. However, meeting performance demands, such as complex geometries and extremely smooth surfaces, remains a major challenge that current nanofabrication methods have yet to overcome. As a result, much of this potential remains the subject of ongoing research.

Survey responses reflect this technological context (**Figure 3**). Participants generally see modest but positive potential in such systems, particularly regarding environmental impact, energy efficiency, and user-centered concerns like health, acceptance, and safety. These cautious assessments seem appropriate, given the lack of concrete data, but they also point to a general belief in the future benefits of the technology.

By contrast, no specific effects on privacy were noted, which is understandable given the indirect nature of the technology. Concerns remain about complexity, maintenance, cost, and the uncertain contribution to technological sovereignty, issues that were also reflected in the expected implementation barriers.

Sensor Technology and Demand-driven Lighting

Reducing nighttime lighting has emerged as one of the most effective strategies for tackling many of today's challenges in urban illumination. Because energy consumption is directly tied to light intensity, lowering light levels offers immediate potential for savings and from an ecological standpoint, dimming is currently the only reliable way to address the diverse needs of different species inhabiting urban environments. Complete shutdowns of outdoor lighting during nighttime hours are especially impactful and have already been

implemented in several European municipalities. However, total darkness can negatively affect user experience and public acceptance plays a crucial role in the success of measures.

To reconcile energy efficiency with user comfort, cities are turning to sensor-based lighting systems. These systems typically rely on passive infrared or radar sensors to detect presence, while preserving user privacy. The goal is to achieve a "minimal-intelligence" control system that responds to environmental changes, distinguishing it from more complex Smart City or IoT-driven solutions. Numerous pilot projects have demonstrated how such systems can successfully balance energy savings with the needs of users [4].

Some advanced systems go beyond simple presence detection by adjusting lighting levels based on real-time information. For instance, street lighting can scale proportionally to the number of vehicles, yielding up to 60% energy savings in low-traffic areas and around 40% in busier zones [23]. Other innovations involve synchronizing multiple luminaires to follow users' movement, creating dynamic light gradients for pedestrians, cyclists, and motorists. Pilot projects using these techniques have achieved energy savings of up to 77% [24].

Nevertheless, the selection of technologies and control strategies must be tailored to the specific conditions of each location. The complexity of implementation, combined with relatively low cost savings in small-scale applications, continues to pose barriers. However, even low-complexity, minimally intelligent systems can offer meaningful improvements to existing infrastructure [25]. Sensor-based lighting can retain most of the energy-saving benefits of full shutdowns while offering the flexibility to respond to emergencies or unforeseen circumstances.

From a technical standpoint, these systems are not only feasible but are increasingly available on the market. PIR sensors are commonly used for simple presence detection, while radar systems are preferred for volume-responsive applications. Although not yet standardized in regulation, demand-responsive lighting is gaining ground in lighting products, supported by a growing base of expertise.

Despite clear advantages over traditional time-controlled lighting, adoption remains limited. High upfront costs for installation and anticipated maintenance remain significant barriers. Importantly, current cost-benefit analyses rarely consider long-term savings at the national scale. While municipalities may reasonably decide against implementation due to short-term budget constraints, this often leads to higher aggregate resource consumption over time. In this light, stronger policy support for demand-responsive lighting would be well justified.

Survey respondents rated both PIR and radar technologies positively (**Figure 4**), particularly in terms of reducing environ-

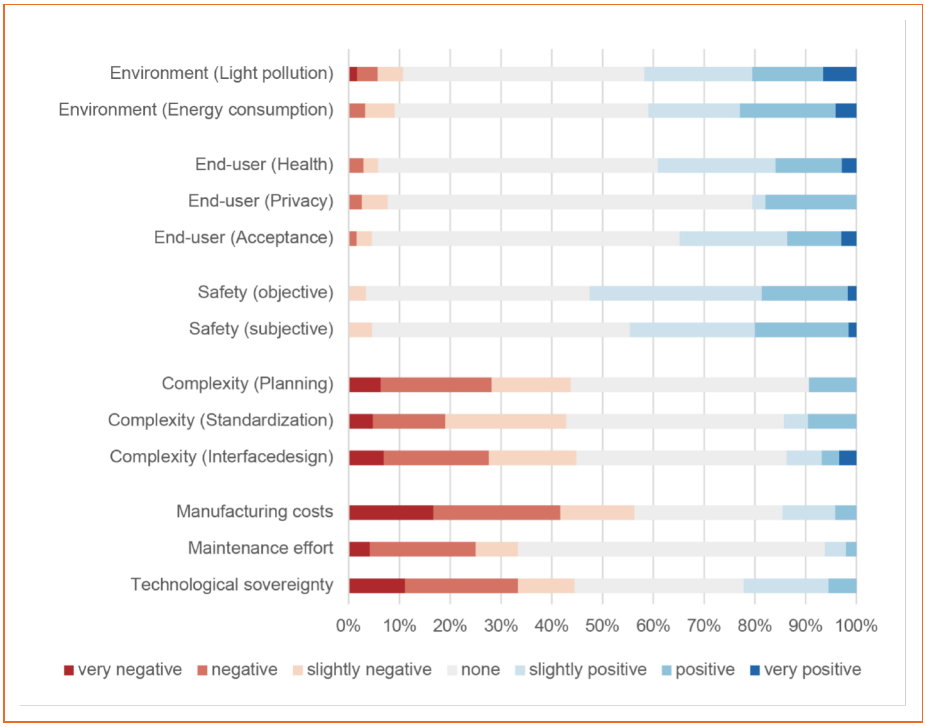

Figure 3: Multidimensional impact assessment of the technology area "nanotechnology-based optical components"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

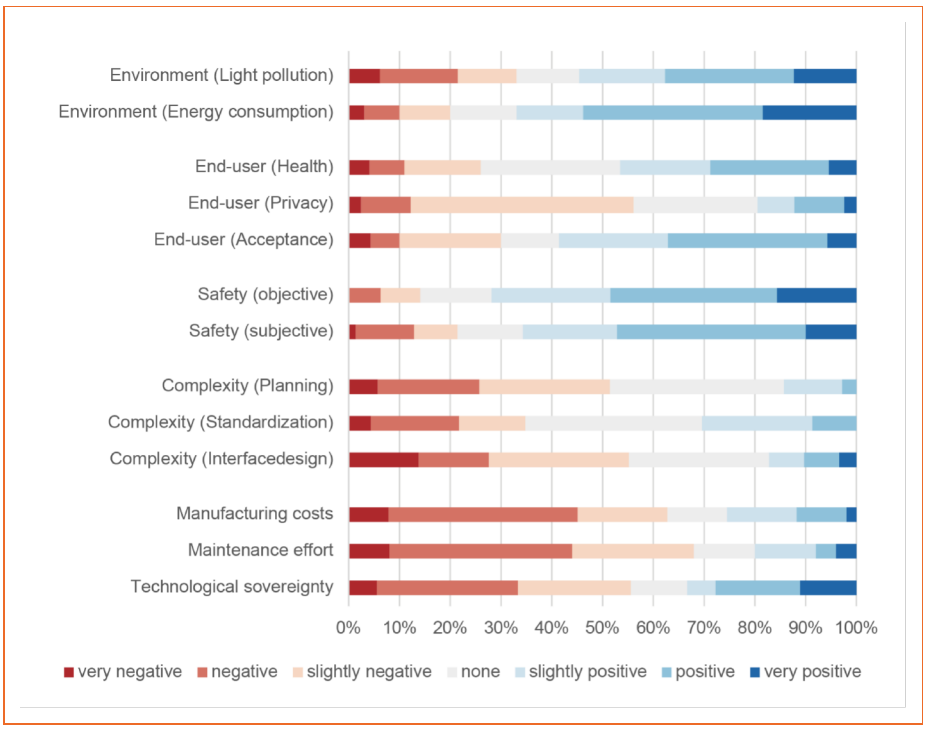

Figure 4: Multidimensional impact assessment of the technology area "sensor technology and demand-driven lighting"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

mental impacts, lowering energy use, and improving health, safety, and user acceptance with approval ratings around 50–60%. Privacy concerns were the most common point of hesitation, as these systems inherently detect presence, raising fears of misuse in criminal planning. However, there is currently no evidence to suggest that such systems increase crime rates.

Compared to full switch-offs, demand-based lighting was perceived as more complex across multiple dimensions, particularly in planning and regulatory frameworks. Although standardized interfaces for sensor integration (e.g., Zhaga) already exist, many respondents still saw interface complexity as a barrier, likely reflecting a gap in technical knowledge. More than 60% cited high costs and maintenance demands as major obstacles.

Finally, views on technological sovereignty were mixed. While the broad market availability of sensor-based systems limits opportunities for competitive differentiation, wider adoption could still support sustainable growth and innovation in the lighting industry.

Smart and Connected Systems

The growing availability of sensors, robust communication protocols, and intelligent control applications is accelerating the development of smart city concepts. By integrating technologies for data collection, processing, and dissemination, cities are better positioned to achieve social, economic, and sustainability goals. A central enabler in this transformation is the Internet of Things (IoT), which facilitates seamless connections between devices, sensors, and networks.

IoT technologies support a wide range of applications across various sectors. In the public sphere, they are particularly attractive to city administrations, as they enable the timely collection of data to enhance service delivery and increase transparency [26]. At the urban level, IoT is used to provide cost-efficient services, improve public transport systems, reduce traffic congestion, and promote safety and public health. On a broader scale, national-level initiatives benefit from IoT through improved energy efficiency, pollution monitoring, infrastructure development, and environmental management [27].

Among the many applications, public lighting stands out as a key pillar of urban innovation. Smart street lighting systems, equipped with sensors, wireless communication, and automated control algorithms, can operate autonomously within IoT ecosystems. These systems can dynamically adjust light intensity in response to traffic flow or weather conditions, while remote access allows for monitoring, fault detection, and environmental data collection [28].

Beyond lighting, interconnected IoT systems offer added value by sharing information across domains, improving services well beyond their original scope. Studies have highlighted potential benefits in areas such as smart parking, energy and water management, infrastructure planning, agriculture, and healthcare [29]. Given the challenges posed by urbanization and traffic congestion, real-time traffic monitoring is especially promising for advancing urban planning and governance [30].

Despite these opportunities, several challenges still hamper implementation. Establishing IoT infrastructure requires significant investment in hardware, connectivity, and data management. The real-time collection of sensitive data also raises serious privacy concerns, necessitating strict compliance with data protection regulations. In addition, ensuring the reliability and security of IoT systems remains a technical hurdle.

Nonetheless, real-world examples show that these challenges can be overcome. San Diego has installed over 3,000 smart streetlights that monitor traffic and environmental conditions to inform urban planning. Los Angeles has implemented an advanced lighting system combining LED technology, IoT sensors, and remote control, leading to a 60% reduction in energy use and millions in annual savings.

These cases illustrate the broader potential of connected lighting systems to enhance urban quality of life. Street lighting offers ideal conditions for rapid rollout due to its widespread presence and existing power supply. Yet, broader market adoption remains limited. Key barriers include high costs, unclear responsibilities among stakeholders, and a lack of comprehensive data management frameworks. Most critically, there is still little incentive for the sector to embrace fully integrated systems. Existing urban lighting objectives can often be met using basic sensor technologies, and greater system complexity could introduce additional costs without clear added value.

This cautious stance is reflected in recent survey findings (**Figure 5**). While respondents recognized environmental and safety benefits, more than 70% cited cost and maintenance as major obstacles. Surprisingly, over half also expressed concerns about technological sovereignty, despite the opportunity for Europe to take a leadership role in smart lighting through forward-looking regulation and data policy.

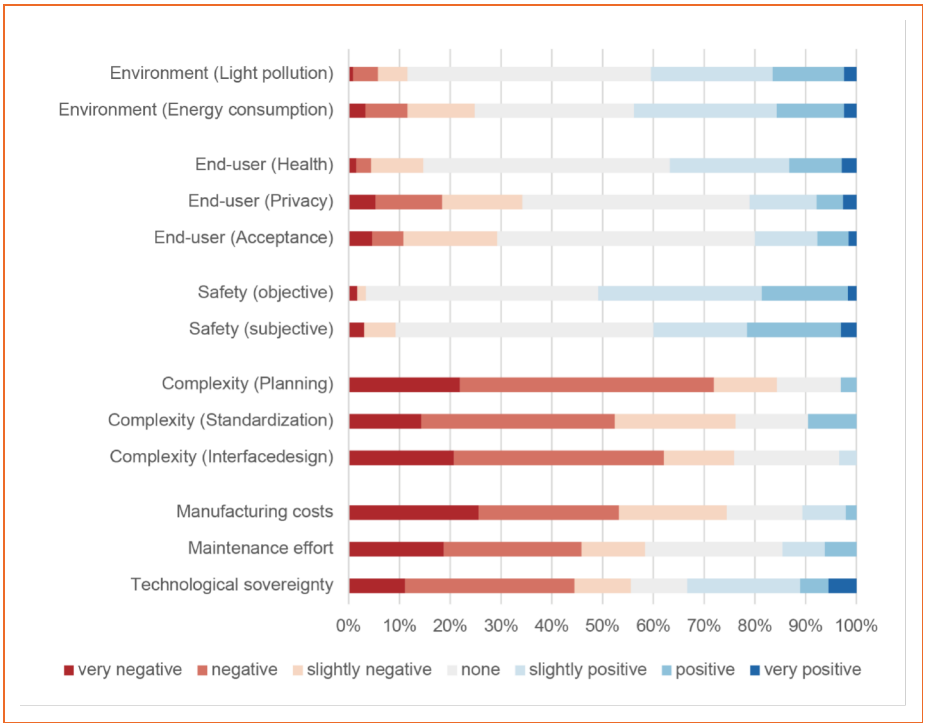

Figure 5: Multidimensional impact assessment of the technology area "smart and connected systems"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

Machine Learning

Outdoor lighting systems inherently involve conflicting objectives, such as enhancing visual quality or ensuring safety, while simultaneously aiming to reduce energy consumption. Due to the complexity of these systems, many environmentally oriented improvements are difficult to achieve through conventional control logic alone. However, the growing availability of real-time sensor data and the rise of machine learning technologies are opening new pathways to address these challenges more effectively.

Contemporary approaches to smart lighting can generally be grouped into two main categories. The first centers on the development of advanced, intelligent street lighting systems. While they share the same foundational goals as sensor-based controls, these systems operate with greater complexity and adaptability. In addition to basic sensors, they often incorporate camera-based technologies to gather richer datasets, enabling more nuanced decision-making. As a result, lighting can be dynamically adjusted not only in response to traffic volume but also to traffic flow and prevailing weather conditions [31]. Moreover, light levels can be fine-tuned through evaluations of sky conditions, offering more targeted dimming strategies than traditional luminance-based methods [32].

The second approach focuses on large-scale, system-wide management. By integrating traffic-aware lighting with predictive modeling, these systems can achieve greater energy efficiency across entire infrastructures [33]. Optimization techniques, such as swarm intelligence, are commonly used to enhance performance [4]. Successful implementation requires robust IoT frameworks, incorporating sensors, connected devices, and wireless communication networks [34]. Studies have not only demonstrated the feasibility of such systems but also highlighted their significant economic advantages [35].

Beyond the scope of lighting itself, machine learning delivers added value within broader, interconnected smart city frameworks. In these contexts, various infrastructure components interact, and sharing data across systems becomes key to developing optimized, cross-sector solutions. Given their widespread presence, lighting systems can serve as valuable data nodes, feeding information into other urban functions, like waste management [36] and water quality [37]. Integrating such systems also offers opportunities to reduce energy use by minimizing redundancy in sensor deployment. Research into “Green IoT” initiatives further supports this goal, aiming to lower device-level energy consumption through hybrid deep learning approaches [38].

Despite these promising developments, implementation remains both technically demanding and resource intensive. Effectiveness depends on access to high-quality datasets, which are often lacking, particularly for variable factors like weather. Additionally, the opaque nature of machine learning decision-making continues to raise concerns, especially in safety-critical areas such as road visibility. Legal responsibility is also a grey area, because if poor lighting contributes to an accident, liability remains uncertain.

Survey results reflect these concerns (**Figure 6**). While participants acknowledged environmental and safety-related benefits, many also highlighted challenges in areas such as planning complexity, standardization, and lack of transparency. Incomplete interface definitions and low market maturity have led to fragmented, costly solutions with high maintenance demands. Moreover, concerns about technological sovereignty remain significant.

Derived Recommendations for Action

Based on the survey results, a set of recommendations was developed (**Figure 7**), structured around three overarching categories, and aligned with the current market maturity of the corresponding technological approach. Depending on the category, the proposed measures either directly address sustainability goals or aim to support further development and research efforts to unlock long-term potential.

A central focus of the recommendations lies on energy efficiency and resource conservation, with the primary goal of reducing greenhouse gas emissions. Although emissions from production and disposal of lighting products are not insignificant, the recommendations concentrate on the use phase, which is responsible for approximately 99% of overall emissions. As such, the proposed measures are clearly directed toward improving energy efficiency. The action plan highlights six main strategies: expanded LED retrofitting, complete nighttime switch-offs, the implementation of demand-based systems, adaptive light distribution, nanotechnology-based manufacturing methods, and the use of biogenic materials. If fully implemented over the next decade, these measures could reduce annual CO_2 emissions by an estimated 60,000 tons. This projection is based on replacing all outdoor lighting systems that still operate with conventional light sources, assuming a complete transition to LED technology. Such a shift could cut Austria’s energy consumption for outdoor lighting by around 30%. The required investment is estimated at €300 to €500 million, with a projected payback period of approximately 10 years.

Beyond energy use, outdoor lighting also has significant ecological impacts, particularly in relation to biodiversity. To address these concerns, a second set of recommendations was formulated to improve environmental compatibility. Scientifically, the knowledge base is already sufficient to support sustainable market implementation. However, the absence of standardized assessment methods and supporting regulatory frameworks continues to hinder progress. The development of these tools and regulations is considered feasible by 2035. Still, without standardized evaluation procedures in place, the potential positive effects of the proposed measures cannot yet be quantified.

A third group of recommendations addresses the increasing relevance of digitalization, focusing on interoperability and technological sovereignty. These measures include concepts such as system connectivity and machine learning applications. Given the complexity of such technologies and their current lack of real-world implementation, these approaches remain largely within the realm of research. Consequently, it appears unlikely that the full potential of enhanced networking and intelligent systems will be realized before 2035.

Conclusion

Outdoor lighting is undergoing a fundamental transformation driven by growing environmental concerns, technological advancements, and evolving societal expectations. As urban areas expand and the demand for sustainable infrastructure intensifies, lighting systems must evolve beyond traditional approaches. A central priority is reducing energy consumption while maintaining or improving lighting quality. Outdoor lighting accounts for a substantial portion of municipal energy use, and the transition to energy-efficient technologies such as LEDs has already yielded notable gains. However, simply switching light sources is no longer sufficient. To meet ambitious sustainability goals, lighting systems must become more adaptive and intelligent, capable of dynamically respond-

ing to real-time environmental conditions and user needs. Sensor-based, demand-driven lighting offers a practical solution, as they can substantially reduce energy use and mitigate negative impacts on wildlife and ecosystems. Yet their adoption remains limited due to high upfront costs, maintenance concerns, and regulatory complexities.

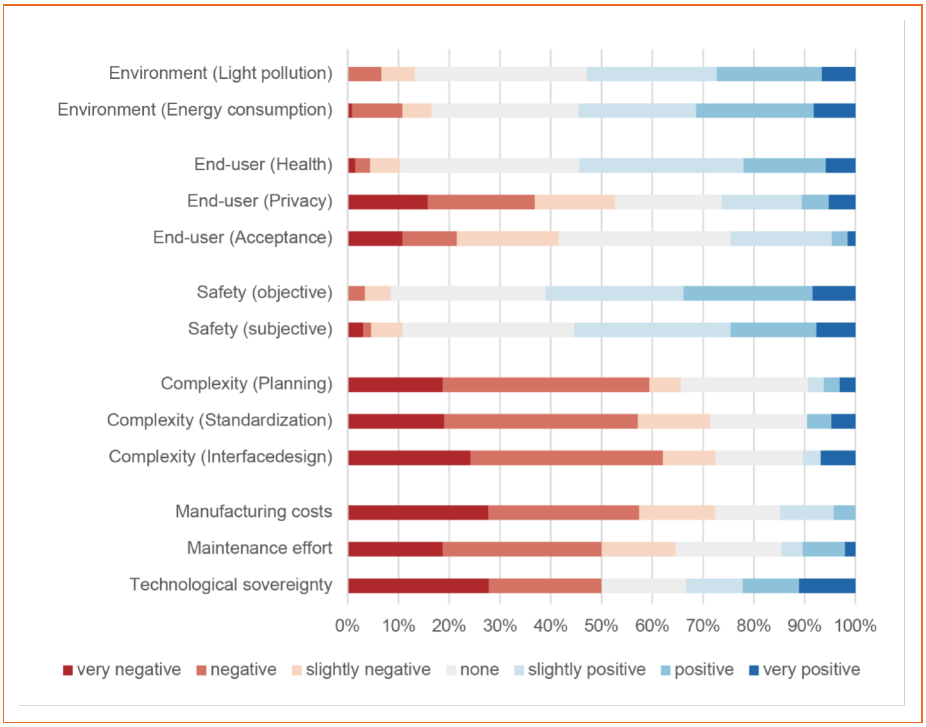

Figure 6: Multidimensional impact assessment of the technology area "machine learning"; each dimension rated on a 7-point Likert scale (1 – very negative impact, 4 – no impact, 7 – very positive impact).

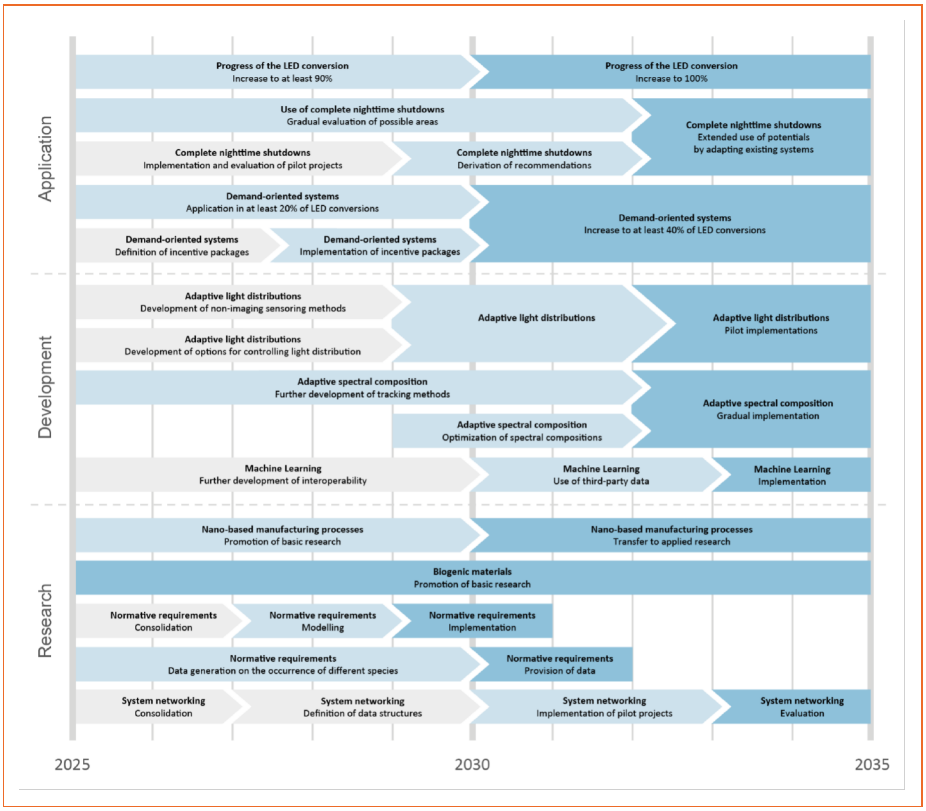

Figure 7: Overview of the action guideline derived from the survey results for promoting the existing potential of outdoor lighting, grouped by application relevance and addressed key technology.

At the same time, digitalization and connectivity are transforming outdoor lighting into a core element of the broader smart city ecosystem. The proliferation of the Internet of Things (IoT) enables streetlights and other lighting assets to collect, share, and analyze data, supporting applications that extend far beyond illumination itself. Smart lighting systems can adapt not only to traffic and weather but also contribute to urban planning, environmental monitoring, and public safety. Machine learning enhances these capabilities by enabling predictive and optimized control strategies, potentially unlocking significant energy savings and improved service delivery at scale. Nonetheless, the complexity and cost of fully integrated smart lighting systems, along with concerns about data privacy, technological sovereignty, and system interoperability, have slowed widespread adoption.

In relation to that, public acceptance and trust are crucial factors in the successful implementation of new lighting technologies. While the survey reveals optimism about environmental and safety benefits, concerns persist regarding cost, maintenance, privacy, and the transparency of automated decision-making processes. Addressing these issues requires not only technological solutions but also clear communication, stakeholder engagement, and inclusive policymaking. Without such efforts, resistance to change may impede progress despite the clear advantages of smarter, more sustainable lighting solutions.

Looking ahead, the trajectory of outdoor lighting technology is defined by a balance between incremental improvements and breakthrough innovations. Strategies such as expanded LED retrofitting, demand-responsive dimming, and adaptive light distribution represent mature, actionable approaches with immediate impact potential. Meanwhile, ongoing research into nanotechnology, machine learning, and fully connected IoT ecosystems holds the promise of transformative gains over the longer term. Realizing this potential depends on sustained investment in research, innovation, and capacity-building, alongside the establishment of robust standards and supportive policy environments.

Importantly, environmental sustainability must remain a guiding principle throughout this transition. Outdoor lighting impacts biodiversity, human health, and climate goals in ways that extend beyond energy consumption alone. The development of standardized assessment methods and regulatory frameworks is essential to en-

sure that new lighting systems deliver genuine ecological benefits and avoid unintended consequences. Collaboration between scientists, industry, regulators, and communities will be critical to designing lighting solutions that harmonize technological capability with environmental stewardship.

In conclusion, the future of outdoor lighting lies in embracing a holistic approach that integrates technological innovation, environmental responsibility, and social acceptance. By harnessing advances in optics, sensors, connectivity, and intelligent control, cities can create urban nightscapes that are safer, more energy-efficient, and more respectful of natural ecosystems. However, achieving this vision requires overcoming current technical and economic hurdles, fostering interdisciplinary collaboration, and committing to long-term strategies that prioritize sustainability alongside innovation. Through these efforts, outdoor lighting can play a pivotal role in building smarter, greener, and more livable urban environments for generations to come. ■

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About Bartenbach
Light is a powerful instrument. It designs spaces – and creates quality of life for the people in them. Increasing well-being, making tasks easier, enriching the atmosphere, promoting social interaction: holistic lighting design does it all. And much more. In this way, energy-efficient lighting solutions can make a direct contribution to your company's sustainability strategy and save costs.

As the market leader for international lighting design, Bartenbach designs and implements sophisticated daylight and artificial lighting solutions from a single source. What makes it special is that all of our concepts are science-based and draw on the in-depth lighting know-how of our research and development. "The Lighting Innovators" – this is not only our claim, but also our promise to our customers.

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About the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)

A key field of action of the BMIMI (former BMK) is transport policy. This includes, in particular, hydraulic engineering with regard to waterways and transport regarding the railways, shipping and aviation. This also comprises the regulation of access to railway infrastructure, ship verification, shipping-specific affairs of hydraulic engineering with regard to waterways, air traffic control, aeronautical meteorological services, advertising for passenger and freight transport, automotive engineering and affairs of the traffic police, accident research, road construction and the construction and maintenance of federal roads.

The BMIMI is also responsible for the management of the equity of the Federal Government in the Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (ASFINAG), and in the Alpen Straßen Aktiengesellschaft and the Österreichische Autobahnen- und Schnellstraßen Aktiengesellschaft, as long as the Federal Government is a shareholder of these companies.

The BMIMI is responsible for hydraulic engineering with regard to the navigable rivers Danube and Morava as well as the Thaya from the state border and other waterways, as well as the water supply and sewerage system, insofar as they do not fall within the scope of a different Federal Ministry, or also for the administration of the Marchfeld Canal.

Issues of commercial passenger and freight transport including the commercial carriage of goods in pipelines with the exception of water pipe affairs are also handled by the BMIMI. Its competence also comprises affairs of the carriage of passengers and goods in plant traffic, the Austrian Federal Railways including the construction and administration of structures and properties of the Federal Government dedicated to the purposes of the Austrian Federal Railways, affairs of the management of the Federal Government's equity in other railway undertakings and in the Schieneninfrastrukturfinanzierungs-GesmbH or affairs of companies that exist for the interests of the rail infrastructure, as long as the Federal Government is a shareholder.

Another focal point for the BMIMI is research and technology development. This includes economic and technical research, insofar as it does not fall within the affairs of the Austrian Research Promotion Agency and the Austria Wirtschaftsservice-GesmbH. The BMIMI also focuses on industrial property rights, particularly the patent and utility model system. Last but not least, outer space affairs also fall within the scope of the BMIMI.

Dipl.-Ing. Johannes Weninger studied architecture at the Leopold-Franzens-University of Innsbruck with focus on architectural theory and worked as an external lecturer and research associate at various universities in Austria and Germany in the field of Artificial Intelligence and Cyberphysical Systems. Until 2018 he was a research associate at the Karl-Franzens-University Graz in the Department of Biological Psychology. Since 2016 he has been working at Bartenbach research on the topics of non-visual light effects, digitization and machine learning. He has been leading Bartenbach's research team since 2022.

MMag. Martina Ascher studied psychology and educational science at the University of Innsbruck. She has been working at Bartenbach research on the topics of visual perception, visual and non-visual light effects and architectural psychology in several national and international research projects since 2008. She completed the academy course for lighting designers at the Bartenbach Lighting Academy (2009) and the course for architectural and residential psychologists at IWAP (2021) and supervised student projects and master's theses at the Bartenbach Lighting Academy in the university course in lighting design (2012-2014).

Maximilian Dick, MSc. studied psychology at the University of Innsbruck. He has been working at Bartenbach research on the topics of visual perception and non-visual light effects in various national and international projects since 2019. From 2020-2023, he also worked at the University of Innsbruck as a research associate in the working group Clinical Psychology I and is currently finishing his PhD there.

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Publisher
Siegfried Luger +43 699 1133 5570 s.luger@lugerresearch.com

Theresa König +43 5572 394489 70 editors@led-professional.com

Elio A. Farina +43 5572 394489 70 editors@led-professional.com

Art & Design
Sarah Rauchlechner +43 680 2305 445 hallo@moments-of-aha.com

Account Manager
Christine Luger +43 699 1133 5520 c.luger@lugerresearch.com

China, Hong-Kong
Lolo Young +852 9792 2081 lolo@castintl.com

Germany, International
Armin Wezel +49 30526 891 92 armin@eurokom-media.de

South Korea
Jung-Won Suh +82 2 78 58222 sinsegi@sinsegimedia.info

Taiwan
Leon Chen +886 2 256 81 786-10 Jeon@jkmedia.com.tw

Benelux, France, Ireland, Scandinavia, UK
Zena Coupé +44 1923 85 25 37 zena@expomedia.biz

USA & Canada
Lesley Harmoning +1 218 686 6438 lesley@lhmandco.com

Jill Thibert +1 218 280 2821 jill@lhmandco.com

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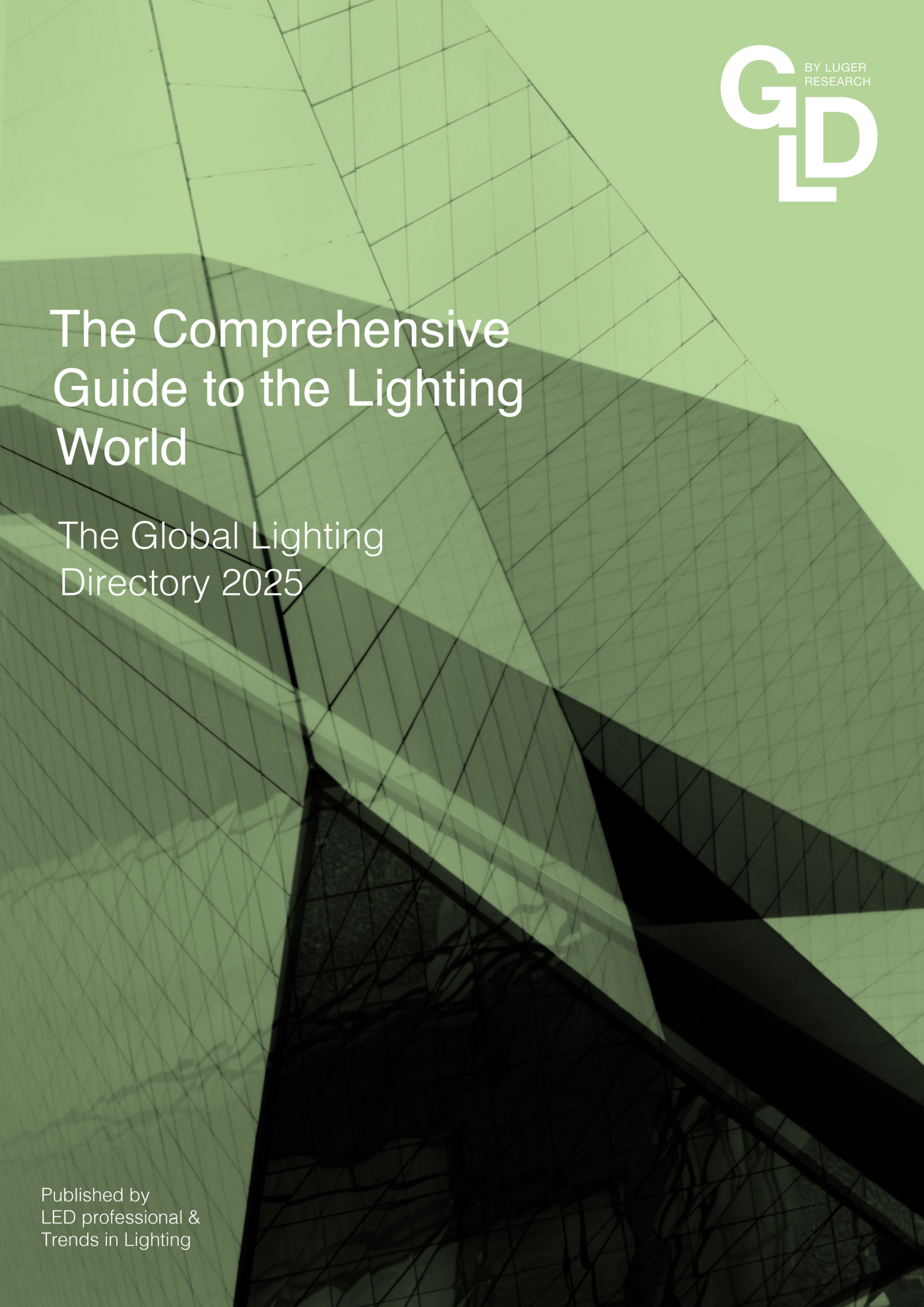

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